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Space Research

Office of Biological and Physical Research September 2002, Vol. 1 No. 4

A Legacy of International Cooperation

Profile: Chiaki Mukai

National Aeronautics and Space Administration

Letter From the Associate Administrator

The theme of this quarter's *Space Research* newsletter is international cooperation, for decades a hallmark of research programs within the Office of Biological and Physical Research (OBPR) and its predecessors. This tradition continues as we enter the International Space Station (ISS) era. While NASA has a long history of engineering and technical cooperation in human spaceflight, beginning with the Apollo Soyuz Test Program, I would like to focus this letter on research collaborations and what this has meant to our biological and physical research programs.

NASA pursues international collaboration in order to strengthen space research both nationally and worldwide. Working together allows us to avoid duplication of effort in developing research capabilities, maximize use of limited technical resources for conducting spaceflight experiments, and capitalize on the best and brightest minds in the world in addressing scientific questions that further human exploration of space and contribute to the quality of life on Earth. Just as a rising tide raises all ships, working together with other nations strengthens all of our programs.

The formative stage of broad international collaboration in biological and physical sciences can be traced back to the early 1980s and the Spacelab program. Four Spacelab missions — the first and second International Microgravity Laboratory missions, the Life and Microgravity Sciences mission, and Neurolab — represented high points in international research coordination on human space missions. International partners on these missions included the Canadian Space Agency (CSA); the French space agency, Centre National d'Etudes Spatiales (CNES); the German space agency, Deutsche Agentur für Raumfahrtangelegenheiten (DARA); the European Space Agency (ESA); and the National Space Development Agency of Japan (NASDA). These missions provided an excellent model for using an international approach to implement complex space research projects.

These are not the only examples of international cooperation in space biology and physical sciences research. NASA flew the ESA-developed Biorack, in which both space agencies sponsored fundamental space biology research. NASA and Russia cooperated on a series of eight automated spacecraft missions. Along with several other space agencies, NASA carried out research programs with the Russian Space Agency (RSA) on Space Station *Mir*. Collaborative research efforts frequently take place on space shuttle/Spacehab missions. All of these efforts contribute to establishing relationships and practices that guide us as we engage in work together onboard the ISS.

The international agreements that establish the rights and responsibilities of the five cooperating space agencies on the ISS set a technical framework for our cooperative efforts. Within that framework are two long-standing working groups that predate the ISS and continue to be instrumental in this process: the International Space Life Sciences Working Group (ISLSWG) and the International Microgravity Strategic Planning Group (IMSPG). These groups have established international approaches to research solicitation, review, selection, and implementation on the ISS. Selection of ISS research projects in physical sciences, biomedical research and countermeasures, and fundamental biology is coordinated using a single set of international scientific merit review panels to evaluate the quality of the science in the research proposals.

International cooperation within OBPR is not limited to scientific research; it also includes cooperative efforts in furnishing the research equipment for the ISS. In addition, cooperative activities in commercial research are being pursued through the Space Product Development Program, including projects with Canadian companies in combustion research and with a Finnish firm (UPM-Kymmene) studying plant growth in space to develop improved timber products, from paper to lumber, on Earth. These projects demonstrate that international cooperation can play a role in our efforts to improve competitiveness in U.S. commercial industry.

Working on an international basis is not without challenges. Cultural, historical, and economic factors can limit progress even in closely coordinated research efforts. Changing political and economic conditions within cooperating countries can present difficulties in maintaining continuity and, in some cases, in meeting commitments. Nevertheless, the challenges are outweighed by the benefits, and international cooperation is an approach that is clearly encouraged within OBPR.

Mary Kicza
Associate Administrator
Office of Biological and Physical Research

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On the cover:
The Payload Operations Center at NASA's Marshall Space Flight Center in Huntsville, Alabama, is the command post for research from around the world to be conducted aboard the International Space Station (ISS). The flags represent each nation involved with the ISS. credit: NASA

Space Research is published quarterly by the **Marshall Space Flight Center (MSFC)** in conjunction with **Hampton University** and **Infinity Technology Inc.** Address comments, newsletter requests, and mailing list updates to Coordinator, Microgravity Research Program Office, Bldg. 4201, SD13, Marshall Space Flight Center, AL 35812. Please provide your name, title, address, and phone number.

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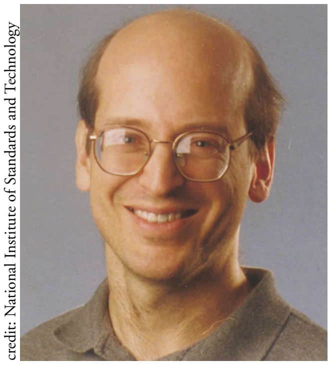
OBPR Researchers Honored for Ground-Breaking Research



credit: National Institute of Standards and Technology

William Mell

credit: Bentley Studios

Cheryl Nickerson

Two NASA principal investigators in the Office of Biological and Physical Research have been honored with the Presidential Early Career Award for Scientists and Engineers (PECASE).

William (Ruddy) Mell, a research assistant professor in the Combustion Research Group at the University of Utah, and Cheryl Nickerson, an assistant professor in the Department of Microbiology and Immunology at Tulane University Health Sciences Center, both received the awards, which are the highest honor bestowed by the U.S. government on exceptional scientists and engineers who are at the beginning of their careers.

Mell was honored for his combustion research in which he "successfully developed a novel simulation code of the effects of g-jitter [disturbances caused by acceleration] from low-gravity facilities, such as a space shuttle or aircraft, on a broad range of combustion phenomena." Nickerson received her award for "innovative research on the effects of simulated microgravity on bacterial gene expression and virulence, which has implications for crew health and the understanding of fundamental processes." (See "Getting From Wild to Mild," p. 16.)

The awards are intended to increase awareness of and encourage participation in careers in science and engineering, to recognize the scientific missions of participating agencies, to enhance connections between fundamental research and national goals, and to highlight the importance of science and technology for the nation's future. The PECASE program was created in 1996 by the National Science and Technology Council, as directed by then-President Bill Clinton.

For more information on Mell's research, visit *http://ncmr04610.cwru.edu/events/combustion1999/papers/87.pdf* on the World Wide Web. For more information on Nickerson's work, visit *http://www.mcl.tulane.edu/departments/microbiology/nickerson.html*.

NASA to Recommend New Approach to Managing the ISS

NASA expects to finalize recommendations soon for a new approach to managing science use of the International Space Station (ISS), including the possible use of a nongovernment agency.

Since March 2002, the ISS Utilization Management Concept Development Team, comprising representatives of several NASA field centers and NASA Headquarters, has been studying various options to most efficiently run the ISS. As a result of its study, which was mandated by Congress, the team has selected a combination of four business approaches: 1) use existing NASA organizations and contractors; 2) work with a nonprofit institute similar to the Space Telescope Science Institute, which manages the Hubble space telescope; 3) create a federal corporation similar to the Tennessee Valley Authority; and 4) use a federally funded research and development center similar to NASA's Jet Propulsion Laboratory.

To arrive at this combination, the Concept Development Team reviewed input received from a NASA-hosted public workshop, attended by about 100 investigators and potential ISS users, held July 11 in Cocoa Beach, Florida. The team then assessed which ISS utilization functions could be performed under each management option. Since then, groups of team members have analyzed the technical and institutional aspects of the working plans, and the full team was scheduled to prepare a report for senior management in late August. NASA expects to send a plan to Congress by the end of the year.

The ISS, one of the largest international science and technology projects in history, will include 27 internal laboratory sites and 31 external platform sites to support U.S. research and development projects alone. Participants from U.S. academia, industry, and government entities will coordinate their work extensively with one another and will keep close ties to the programs of international partners in Canada, Europe, Japan, and Russia.

The latest details and presentations on the ISS utilization management concept are on the World Wide Web at *http://spaceresearch.nasa.gov/research_projects/ngo.html*.

STS-107 Launch Delayed

A plan to repair the space shuttle orbiters and resume mission operations sets the launch of research mission STS-107 no earlier than January 2003. The shuttle fleet was temporarily grounded in June when an inspector noticed almost invisible cracks in the main hydrogen fuel line on Space Shuttle *Discovery* following its June mission to the International Space Station (ISS). Inspections revealed similar cracks in at least one propellant line of each orbiter.

After careful analysis, NASA elected to fix the engine problem by welding and polishing the cracks to return the metal liners to their original condition. Repairs started in early August; space shuttle flights are to resume in October.

Because of the delays, and the discovery of cracked bearings in the crawler transporters, NASA had to adjust the launch lineup to meet conflicting requirements. First priority went to maintaining the pace of work on the ISS, including replacing the ISS Expedition 5 crew with Expedition 6. Restraints set by the angles of sunlight falling on the ISS, the Leonids meteor shower, and the replacement of the Soyuz capsule on the ISS left no opportunities to fly STS-107 in the original sequence, so it was moved behind STS-112 and STS-113. In addition, *Columbia*, the STS-107 orbiter, uses liners made of stainless steel rather than the Inconel used on the other orbiters' propellant lines, so *Columbia*'s repair procedure will be finalized after the other orbiters are fixed.

credit: NASA

Ken Tauer of the United Space Alliance inspects the flow line on *Columbia* after the engines were removed. The inspection results from the discovery of small cracks in the liquid hydrogen flow liners in two other orbiters.

OBPR Research Information Now Available en Español

Physical and biological science enthusiasts who communicate in Spanish can now read about NASA-sponsored research in these areas on the World Wide Web at *http://ciencia.nasa.gov/PhysicalScience.htm*. The web site, a link from the main Ciencia@NASA web page, covers research sponsored by NASA's Office of Biological and Physical Research (OBPR).

At the site, readers can learn about fundamental and applied research being conducted in the life and physical sciences, including studies sponsored solely by NASA as well as those supported jointly by NASA and private funds. Readers also can subscribe to automatic notices announcing when the web site is updated with new articles.

In addition, visitors to the site can connect to the main Ciencia@NASA page, which contains links to other areas of NASA research such as space science, astronomy, living in space, Earth science, and jet propulsion. The English counterpart of the main web site, Science@NASA, may be found at *http://science.nasa.gov*. This English site also supplies links to non-NASA-sponsored web sites that translate some of the information from Science@NASA into other languages, including Danish, Dutch, French, Italian, Korean, Malay, Portuguese, and Spanish.

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Ciencia @NASA

Ciencias Biológicas y Físicas

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El ambiente del espacio es un lugar **muy difícil para trabajar. Al** mismo tiempo, ofrece un ambiente de caída libre con baja gravedad, que nos permite entender como se forman los materiales, como se desarrollan los procesos biológicos, y como interactúan diferentes formas de materia. Ciencia@NASA lo lleva a la Estación Espacial Internacional y otros laboratorios en el espacio, para que usted conozca por sí mismo cómo la investigación espacial obtiene beneficios que serán utilizados aquí en la Tierra

Cristal formado por vapores, durante la misión internacional: Microgravity Laboratory-1

reportajes

Extraños Esqueletos - 19 de junio :
biología elemental
En lo profundo de nuestras células, esqueletos flexibles perciben los efectos de la gravedad... y responden de maneras inesperadas.

Sembrando Semillas en Campos Magnéticos - 15 de mayo :
biología elemental
Los científicos esperan que un inusitado experimento, programado para ser puesto en órbita por el Transbordador Espacial este verano, revele cómo las plantas pueden determinar dónde es "arriba" y "abajo".

Tictac, Reloj Atómico - 8 de abril :
física
Los científicos están construyendo relojes atómicos que funcionan con una precisión inconcebible. Estos instrumentos beneficiarán a los agricultores, físicos y viajeros interestelares.

vínculos de biología y física

reportajes recientes

29 de marzo:
Antibióticos del Espacio - Los tubos de ensayo con bacterias producen más antibióticos en el espacio que en la Tierra.

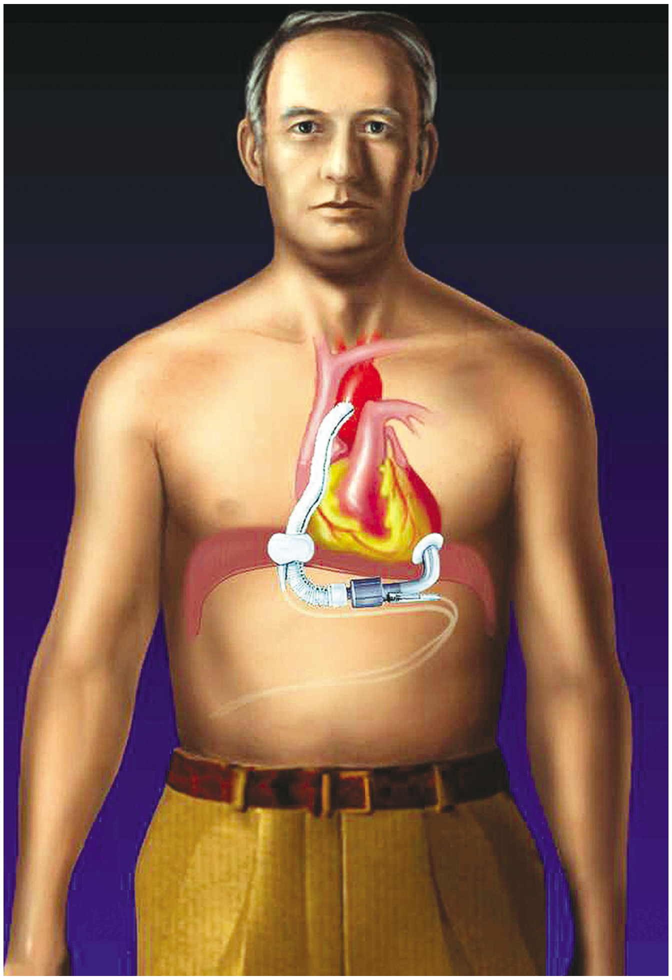
27 de marzo:
Domesticando ¡los Fotones! - Los investigadores han atrapado un pulso de luz dentro de una cámara de cristal -- y luego lo han soltado, intacto.

14 de febrero:
Remiendos para un Corazón Herido - Investigadores han cultivado trozos de tejido que laten y responden como lo hace un corazón humano.

1 de febrero:
Exterminando el Ántrax - Investigaciones destinadas a hacer crecer plantas en el espacio, han permitido construir un aparato que ataca y destruye patógenos.

credit: NASA

DeBakey Wins Invention of the Year Award



credit: MicroMed Technology, Inc.

The MicroMed DeBakey Ventricular-Assist Device acts as a "bridge to transplant" by assisting a weakened heart while the patient waits for a heart transplant.

Heart surgeon and inventor Dr. Michael DeBakey recently received the NASA Commercial Invention of the Year award for the MicroMed DeBakey Ventricular-Assist Device (VAD)®. A world-renowned cardiovascular surgeon known to many as the father of modern cardiovascular surgery, DeBakey was honored for his pioneering work on the device. The VAD is used to support a weak heart while the patient waits for a heart transplant.

The design of the MicroMed DeBakey VAD is partly based on that of the fuel pumps used in the main engines of the space shuttle. Development of the device originated from talks between DeBakey and one of his heart transplant patients, David Saucier, a NASA engineer. Six months after his 1984 heart transplant, Saucier and fellow NASA engineers James Akkerman, Bernard Rosenbaum, Gregory Aber, Richard Bozeman, and Robert Benkowski met with DeBakey and his team. Together they created a small battery-operated pump that weighs less than four ounces but is worth its weight in gold to patients with congestive heart failure.

The VAD works by pumping blood from the left ventricle through a titanium inflow cannula, or tube, inserted into the lower corner of the left ventricle, the heart's largest chamber. Once through the pump, blood flows back to the body through a Dacron outflow graft sewn to the ascending aorta, the main artery leading out of the heart. By taking on most of the work of a weakened heart, the VAD supplies the rest of the body with the blood needed by the other organs and thereby increases the chances that a patient will survive until a new heart becomes available. The device could also be used permanently to strengthen and support a weakened heart if a transplant were not an option, or used temporarily to give a patient's heart the chance to heal and recover. Clinical trials for the device have already begun in Europe and the United States, with more than 165 devices implanted successfully so far.

For more information on the MicroMed DeBakey VAD, visit *http://www.methodisthealth.com/vad/index.htm* or *http://www.micromedtech.com/* on the World Wide Web. For additional information about DeBakey, go to *http://www.methodisthealth.com/debakey/index.htm.*

King Receives AIAA Award for Combustion Research

credit: NASA

NASA scientist Merrill K. "Mickey" King recently received the American Institute of Aeronautics and Astronautics (AIAA) Energy Systems Award for 2002. This award is presented annually by AIAA to scientists who have made a significant contribution to the field of energy research, specifically in the application of engineering solutions to problems of energy management.

King, who is the enterprise scientist for combustion science within the Physical Sciences Division of the Office of Biological and Physical Research, received the award in recognition of his research in microgravity combustion and energy systems involving solid fuels. He is known for his work in the fields of propulsion, combustion, and energy systems improvements as well as for his contributions to the areas of microgravity combustion, solid propellants, kinetics, advanced energy conversion, and novel materials.

Born in Claymont, Delaware, King received his B.S., M.S., and Ph.D. in chemical engineering from the Carnegie Institute of Technology (now Carnegie Mellon University) in Pittsburgh, Pennsylvania. He worked for Atlantic Research Corporation from 1964 to 1991, then joined the National Science Foundation in 1991 as program scientist for their combustion and thermal plasmas program. In 1993, he moved to NASA Headquarters as the enterprise scientist for the microgravity combustion science program.

For more information on AIAA, go to *http://www.aiaa.org/index.hfm* on the World Wide Web. For additional information on NASA microgravity combustion research, go to *http://microgravity.grc.nasa.gov/combustion/index.*

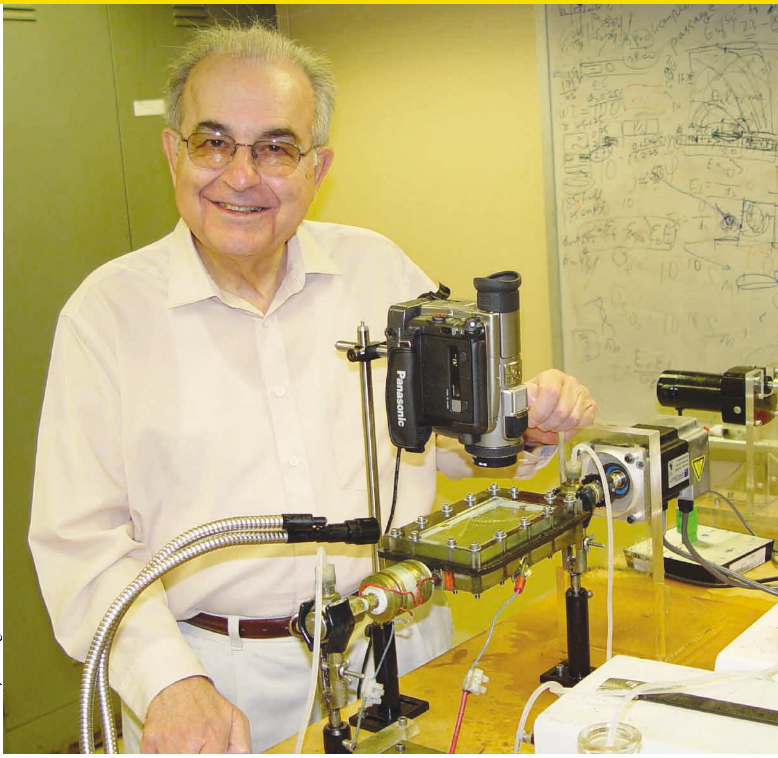
Acrivos Awarded President's National Medal of Science

Principal Investigator Andreas Acrivos was recently awarded the President's National Medal of Science for his lifelong study of fluid dynamics. The medal, awarded by U.S. presidents to nominees reviewed by the National Science Board, is the nation's highest honor given for lifetime achievements in scientific research.

Acrivos was recognized for his work in helping to establish the field of suspension mechanics (the mechanics of substances suspended in but not dissolved in a fluid) and for his contributions to the modern theories of fluid mechanics and convective heat and mass transfer. He is widely recognized as being a pioneer in his field who opened whole new areas of study within fluid dynamics.

Acrivos's current research involves the study of rheology (the analysis of the deformation and flow of matter), electrorheology (the study of how an applied electric field affects the deformation and flow of matter), and the impact of electric fields on particle motion. For the past three years, he has been studying flowing suspensions for NASA. Most recently, in support of NASA and the Office of Biological and Physical Research (OBPR), he has served on the International Space Station (ISS) Management and Cost Evaluation Task Force, which provided recommendations on the ISS Program, and the Resource Maximization and Prioritization Task Force, which provided recommendations on OBPR research activities.

Born in Greece, Acrivos graduated from Syracuse University in 1950 with a B.S. in chemical engineering and earned his M.S. and Ph.D. from the University of Minnesota in 1951 and 1954, respectively. He was on the faculty at the University of California, Berkeley, from 1954 to 1962; taught at Stanford University from 1962 to 1987; and moved to City College of New York in 1988.



credit: City College of New York/CUNY

Principal Investigator Andreas Acrivos was awarded the President's National Medal of Science for his help in establishing the field of suspension mechanics.

For more information on the National Medal of Science, go to *http://www.nsf.gov/nsb/awards/nms/start.htm* on the World Wide Web. For more information on Acrivos's NASA research, go to *http://research.hq.nasa.gov/taskbook/search/retrieve_task.cfm?task_id=314.*

Task Force Recommends Research Priorities for OBPR

The Research Maximization and Prioritization (ReMaP) Task Force has performed an independent external review and assessment of research productivity and priorities for the entire scientific, technological, and commercial portfolio of NASA's Office of Biological and Physical Research (OBPR). The recommendations provide important guidance on how to maximize the scientific returns on many NASA programs, including the International Space Station (ISS).

ReMaP Chair Rae Silver and Co-Chair David Shirley wrote in their cover letter, "We believe that the findings and recommendations in this report will enhance the probability that a credible and productive research program can be established for OBPR, beginning with current ground-based capabilities, access to the Shuttle for research purposes, and ISS US Core Complete configuration, and continuing with an expanded research program through significant enhancements to the ISS research capability."

The ReMaP Task Force ranked research topics by priority, with each priority comprising medical, medical/biological, biological, and physical research topics. The highest priority research in OBPR spans two broad categories — that which enables human exploration of space and that which has intrinsic scientific merit. The task force noted that the majority of OBPR research falls in one or both of these categories and that it is NASA's responsibility to prioritize these categories. Members of the task force recognized the need to enhance ISS research capabilities in order to accomplish this research.

The ReMaP Task Force also considered commercial space research in their deliberations, noting that it is public policy for NASA to facilitate the commercial use of the ISS and that commercial research follows additional selection criteria.

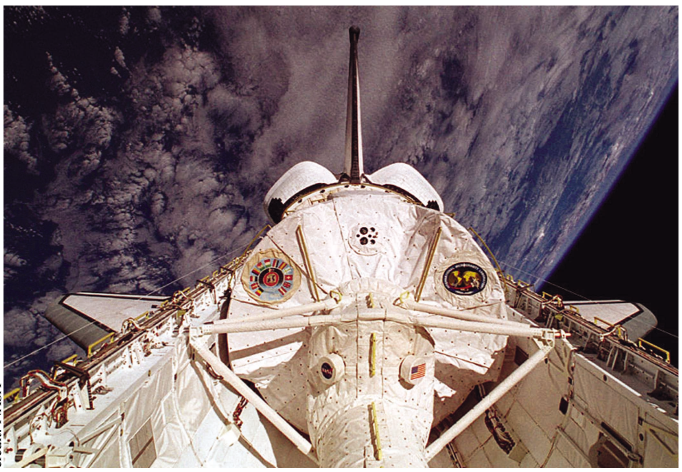
The task force encouraged NASA to continue coordination with the ISS international partners, and in particular to expedite the development of the ISS Centrifuge Facility, currently provided by NASDA, the Japanese space agency. Other ReMaP Task Force findings and recommendations focused on the OBPR organization and management with an emphasis on conducting interdisciplinary research, exploring alternative solicitation methods, and attracting quality scientists.

The latest ReMaP information is online at *http://www.nasa.gov/newsinfo/remap.html*.

Spacelab to Space Station: A Legacy of International Cooperation

As people move toward fully realizing the research opportunities afforded by the International Space Station and look ahead to the next generation of hardware development and research to be conducted, they can look back on the earliest cooperative efforts, like Spacelab, and reaffirm that space truly is an international arena.

Say the words "space race," and pretty much anyone in the United States, young or old, will think of the Cold War competition between the United States and the former Soviet Union to be the first to land a human on the Moon. Most people would also probably believe that during that period, from the late 1950s to the early 1970s, international cooperation in space wasn't ranked high on anyone's priority list.



credit: NASA

Spacelab, designed to fit in the space shuttle cargo bay, marked the beginning of real international cooperation in space. European and American collaboration on the design of and research aboard Spacelab paved the way for making the vision of a space-based multinational research community — currently embodied in the ISS — a reality.

"But international cooperation has always been there at the policy level at the White House, from Kennedy on," says Jeff Bingham, senior adviser to the Administrator for policy and history at NASA Headquarters in Washington, D.C.

In fact, Bingham notes that on September 20, 1961, President John F. Kennedy, in a speech at the United Nations, proposed that the United States and the Soviet Union work together on a joint mission to reach the Moon. Kennedy's comments were the outgrowth of a conference Kennedy and Soviet leader Nikita Khrushchev had attended in Vienna, Austria, earlier that year. But at that time, Kennedy's proposal went unheeded, and the stage was set for the race that followed.

Science Fiction Foretells Reality

Meanwhile, in the entertainment industry, at about the same time that the space race was truly heating up, a cult classic was born. Gene Roddenberry, a former police officer, developed a television program that he called *Wagon Train to the Stars*. This program, ultimately retitled *Star Trek*, ran for three years before being cancelled and going into syndication in 1969 — shortly before Neil Armstrong walked on the Moon.

While the United States and the Soviet Union were racing to the Moon, *Star Trek*'s characters were travelling to galaxies far beyond. That original *Star Trek* series may now be viewed as somewhat politically incorrect, but the cast of characters certainly foretold one aspect of the real future in space. On the bridge of the starship *U. S. S. Enterprise* were Americans, a Japanese, a Russian, and a Vulcan. Engineering was handled by a Scot. Later versions of *Star Trek* went even further, adding characters from other planets in faraway galaxies. A federation of cultures joining together to explore space for peaceful purposes was the premise for the adventures of the *Enterprise*'s crew. International collaboration in real life may have begun for more practical reasons, but it has developed to be as inclusive — barring extraterrestrials — as Roddenberry envisioned it.

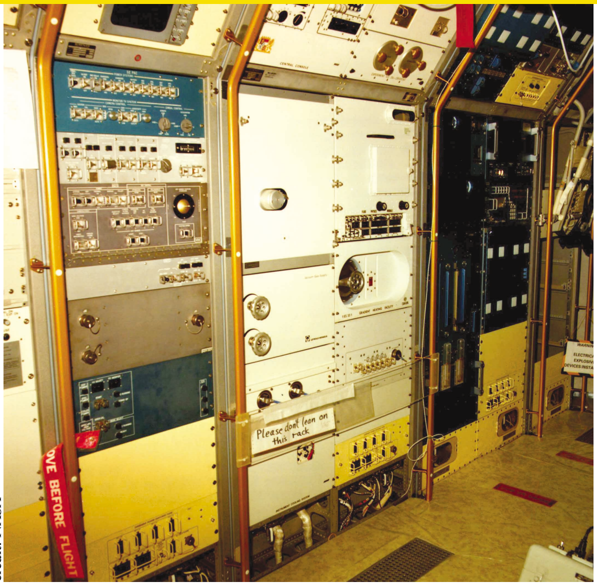
Back to the Plan

In the real world, the United States was redefining its space program, identifying its purpose and determining its next step. Says Bingham, "When NASA was established, its first long-range plan, issued in January 1959, included a permanent space station." And using space for research was a part of that vision.

But the program took a detour from the space station path, as Charles Walker, space systems business development and marketing senior manager for the Boeing Company and a former payload specialist, noted at the Spacelab Accomplishments Forum, held in Washington, D.C., in March 1999. The early human programs like Mercury included some basic research, but then political goals — such as being the first country to put a person on the Moon — overtook research goals. Walker also pointed out that once the political aims of the Apollo program had been met, the U.S. space program returned to its research orientation, developing a temporary space station, *Skylab*, using Apollo hardware and systems.

"[*Skylab*] offered spacious accommodations for researchers," said Walker. "Solar physics, Earth resources, life sciences, and space technology were all investigated there. It was an important step along the way, taking us from just intellectual inquiry about this environment to one in which we have continuing hands-on research."

Despite the success of *Skylab*, political and budgetary realities prevented any action on a permanent space station from going forward. In 1972, approval was received for the space shuttle program, known as the space transportation system (STS), in which a reusable vehicle would make routine trips to orbit lasting several days to several weeks. At around the same time, the idea for Spacelab, a pressurized laboratory module that would fit in the



credit: NASA

The Spacelab module provided a shirtsleeve research environment, with research equipment contained in racks, seen here, with handrails attached for the astronauts to get around the lab.

space shuttle cargo bay to provide an environment for conducting hands-on research, was born.

Walker noted that with Spacelab, real international cooperation in space began. The first Spacelab module was to be given to NASA by the European Space Research Organization (ESRO, which later merged with another organization to become today's European Space Agency, or ESA). In exchange for building the module and system of removable cargo pallets, the European space research community was to receive use of 50 percent of the Spacelab's first flight.

Blazing an International Trail

The building of Spacelab by Europeans to fit into an American-designed, American-built space shuttle was an enormously complex project, not without its difficulties and pitfalls. The Europeans had not been involved in human space travel prior to that time, nor had they worked on a space engineering project that large. Numerous cultural differences had to be overcome, not the least of which were differences in spelling and measuring systems. Europeans working on Spacelab had to convert American inches to millimeters and had to be aware that Americans used decimal points in the places where Europeans used commas.

The European work also required a great collaborative effort. At the Spacelab Accomplishments Forum, Klaus Berge, director of space projects at the Deutsches Zentrum für Luft- und Raumfahrt (DLR) and a former managing director and deputy director general of the German space agency, Deutsche Agentur für Raumfahrtangelegenheiten (DARA), noted that work on Spacelab was truly Europe-wide, with subcontractors in Austria, Belgium, Denmark, France, Ireland, Italy, the Netherlands, Spain, and the United Kingdom, in addition to Germany.

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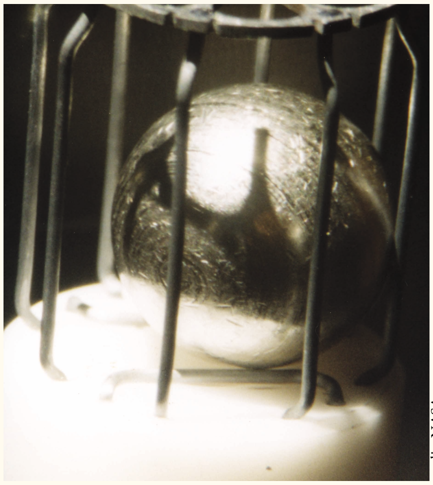
The Walls Come Down: Collaboration in Containerless Processing

Developments in the research field of containerless processing can serve as an illustration of how international cooperation evolved from the Spacelab era to make collaborative use and even design of space research facilities the norm.

Why Levitate?

One use of containerless processing, or the solidification of a liquid material in the absence of a container, is for producing metals and alloys through undercooling, the process whereby molten materials are cooled below their normal freezing point and yet still remain liquid. During normal cooling of a liquid, solidification begins where the liquid touches some impurity or other substance, such as a container wall or another object, which causes a few atoms or molecules of the liquid to freeze. For example, water cooling in an ice tray in a freezer begins to solidify where the water touches the side of the ice tray. However, if a pure liquid is manipulated in such a way that it does not touch anything, it can be cooled below its freezing point without freezing actually occurring. When the liquid does finally freeze, it does so nearly instantaneously, emitting a flash of light, and the result is a solid that can have properties different from those of solids produced by a normal cooling process.

Although ground-based research on undercooling can be conducted by levitating samples with electrostatic or electromagnetic forces, microgravity offers several advantages. The main benefit is the lack of gravity's influence on the levitated sample. Even though Earth-based levitated samples appear to be defying gravity, gravity still influences the physical processes, such as convection, found in the liquid sample being studied. Also, in the case of an electromagnetic levitator, levitation requires the input of such large amounts of energy to overcome gravity that the sample is heated to extreme temperatures, and this heating can also affect scientific results. In microgravity, a sample can be self-contained and studied in the near absence of gravitational forces.



credit: NASA

This metal sample, which is approximately 1 cm in diameter, is typical of the metals that were studied using the German-designed electromagnetic levitation furnace TEMPUS aboard the IML–2, MSL–1, and MSL–1R missions. The sample is shown inside the metal cage in which it was levitated during the U.S. and German experiments to study viscosity, surface tension, and other physical properties of metals and metal alloys.

TEMPUS Fugit

For the second International Microgravity Laboratory mission (IML–2), Germany provided an electromagnetic levitator, TEMPUS, for research in containerless processing. According to Jan Rogers, facility scientist for the ground-based Marshall Electrostatic Levitator and former U.S. project scientist for TEMPUS on the Microgravity Sciences Laboratory–1 (MSL–1) mission and its reflight, MSL–1R, Germany built the levitator for the IML–2 mission as part of an agreement with NASA in which NASA would provide the flight opportunity for the facility in exchange for some experiment time for U.S. researchers.

continued on page 1

Astronaut David Hilmers is the test subject sitting in the rotator chair for the Microgravity Vestibular Investigations (MVI) on IML–1, which flew in January 1992. In the MVI, researchers from Canada, the United States, and other countries examined the effects of orbital flight on the human orientation system to obtain a better understanding of the mechanisms of adaptation to orbit.

credit: NASA

The first Spacelab, which flew on STS-9 in 1983, carried more than 70 experiments spanning a number of research areas — astronomy and solar physics, space plasma physics, atmospheric physics, Earth observations, life sciences, and materials science — and utilized 38 experiment facilities. One of those facilities, the Materials Science Double Rack, was used by the crew to conduct 30 experiments for 44 investigators in the areas of crystal growth, fluid physics, and metallurgy.

The 15 life sciences experiments included research on the radiation environment and on measuring central venous pressure, as well as on human immune responses, production of red blood cells, and changes in the vestibular system (the organs that allow the body to recognize its orientation in space) in a microgravity environment.

This flight of Space Shuttle *Columbia* also marked the flight of the first astronaut to represent ESA in space, Ulf Merbold of Germany.

In early planning, it was agreed that 50 percent of research time, crew time, power, and mass would be allocated to the Europeans, and the first Spacelab mission was viewed as two payloads, the NASA half and the European half. In reality, according to forum participant Harry Craft, vice president of information systems for COLSA Corporation in Huntsville, Alabama, there was a lot of give and take, and by the time Spacelab flew, everyone had begun to treat it as one science payload. He added that on subsequent missions, the science community was much more involved in deciding how to divide resources.

credit: NASA

Onboard *Discovery*, the seven crewmembers of IML–1 pose in the Spacelab module for the traditional in-space portrait. Pictured clockwise from the top are Commander Ronald Grabe, Payload Commander Norman Thagard, Payload Specialist Roberta Bondar (CSA), Mission Specialists William Readdy and David Hilmers, Pilot Stephen Oswald, and Payload Specialist Ulf Merbold (ESA, Germany). Merbold was the first astronaut to represent ESA in space.

A Cooperative Mission Series

After the success of the first Spacelab mission, officials at NASA and ESA put together a science working group to explore the joint utilization of Spacelab for a four-mission series called the International Microgravity Laboratory (IML). The IML missions are a particularly shining example of the type of international research collaboration that occurred during the space shuttle era.

In the fall of 1984, representatives from Canada, France, Germany, Japan, and the countries represented by ESA met with NASA to work out the details of the IML series of flights. The first IML flight was scheduled to launch in May 1987, but the loss of Space Shuttle *Challenger* put human spaceflight on hold for nearly three years. When space shuttle operations began anew, the backlog of payloads awaiting flight necessitated reducing the number of IML missions from four to two, and the first IML mission (IML–1) was launched on STS-42 in January 1992.

Mike Sander, now project manager of the Mars 2009 Smart Lander Project, was director of the Spacelab Payloads Engineering Division prior to the IML–1 flight. Says Sander, “One of the first things I did [after being named director] was try to take an inventory of what equipment we had to take advantage of this new facility [Spacelab]. It was pretty clear that there was very little hardware available to investigators in the U.S. materials world and relatively little money in that division to build additional instrumentation.

“So with this new hat on, I went to Europe and was talking to [a German ESA member], and he started wringing his hands at having the Materials Science Double Rack [used on the first Spacelab mission], as well as other equipment, but not having flight opportunities. It wasn’t rocket science to come up with a notion that says, ‘Look, here’s this really good European equipment, and here’s this dearth of equipment in the U.S., but we’re rich in flight opportunities.’

“So we basically came up with a formula that said if the Europeans kicked in their equipment and if the U. S. science community could propose experiments that made good use of that equipment, then we could put together a deal where the Europeans would give half of their operating time on their equipment to U.S. investigations, and we would then fly the European hardware in this dedicated International Microgravity Lab series.”

Indeed, IML–1 flew with research from more than 200 scientists from 13 countries. Six international space science research organizations were represented: the Canadian Space Agency (CSA); the DLR; ESA; the French space agency, Centre National d’Etudes Spatiales (CNES); NASA; and the National

credit: NASA

Astronauts Roberta Bondar, of the Canadian Space Agency, and Stephen Oswald, of NASA, work in the Spacelab module during the IML–1 mission. IML–1 flew research for more than 200 scientists from 13 countries and included both physical and life sciences experiments.

credit: NASA

Onboard Space Shuttle *Columbia* on the first day of the IML–2 mission, Mission Specialists Leroy Chiao (top) and Donald Thomas (bottom) start life sciences experiments in the Rack 5 Biorack. Chiao is placing a sample in the Biorack incubator, while Thomas handles a sample in the Biorack glovebox, which is used for preparing samples for the Biorack or the German-designed slow-rotating centrifuge microscope (NIZEMI).

Space Development Agency of Japan (NASDA). ESA provided Spacelab, NASA provided Space Shuttle *Columbia* and a second Spacelab flight set, and the remaining organizations contributed various types of hardware.

Among the physical sciences research conducted during the mission were experiments studying liquid-vapor critical point transitions, electrophoresis, the physics of gas bubbles, metal alloys, and protein crystal growth. Many of the life sciences experiments were based on results of previous space investigations. Of particular interest to researchers were the adaptation processes the human body undergoes when exposed to microgravity. Studies of the vestibular, nervous, circulatory, skeletal, muscle, and metabolic systems were undertaken on IML–1. In addition to human-based investigations, researchers studied the effects of microgravity and radiation on the development, behavior, and reproduction of slime mold, yeast, hay-bacillus, and *Drosophila* fruit flies, as well as their effects on different mammalian cell cultures.

A second International Microgravity Laboratory (IML–2) mission flew on STS-65 in July 1994. A total of 15 countries conducted 77 research experiments in the areas of materials science, fluid physics, life sciences, and bioprocessing.

The IML missions carried not only international research but also international crews. IML–1's seven-member crew included Payload Specialists Roberta Bondar from Canada and Ulf Merbold from Germany. Japanese astronaut Chiaki Mukai (see profile, p. 27) made her first spaceflight aboard IML–2; she later became the first female Japanese astronaut to fly into space twice.

The Spacelab Experience

Over its 17-year flight history, the Spacelab program hosted payloads for practically every research discipline that NASA pursues. In all, 19 space shuttle missions carried life and microgravity sciences research into orbit and resulted in more than 750 experiments and more than 1,000 peer-reviewed articles, as well as numerous talks, abstracts, and master's and doctoral theses.

The international nature of the program continued and included a mission that was dedicated solely to Japanese research (Spacelab J) and two missions dedicated to German research (Spacelabs D-1 and D-2). A Spacelab module was even flown as a cargo

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The Walls Come Down *continued from page 9*

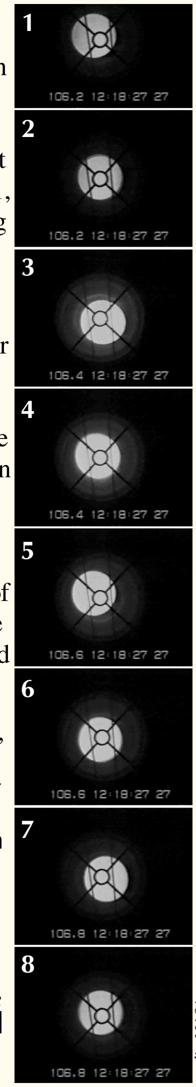
The TEMPUS facility was designed to use magnetic fields to position a gumball-sized metal sample in the center of an experiment chamber. The sample could then be heated, and changes that occurred during the heating process could be observed. Additionally, the levitation chamber could be used for undercooling the samples. These various processes — heating, undercooling, and their impacts on the surface tension and viscosity of the sample — could be studied by researchers in order to learn more about a metal's properties. Such information could then be applied to fine-tuning the processing of metal products and alloys on Earth.

TEMPUS was tested on sounding rockets and on the KC-135 parabolic aircraft before its first flight on the space shuttle. Unfortunately, during IML–2 the coils that allow levitation had accidentally become misaligned, and samples were pushed off-center and into the walls of their cages, which caused them to cool instantly. Enough valuable data were collected, though, to warrant the reflight of the levitator aboard MSL–1 and MSL–1R with great success.

TEMPUS was used by both U.S. and German researchers on its three flights aboard Spacelab. According to Rogers, both formal and informal research collaboration occurred as a result. Two of the formal co-investigations that were undertaken were the study of the undercooling of steel by Merton Fleming's group at the Massachusetts Institute of Technology, which worked with Wolfgang Löser, of Dresden, Germany, and the study of quasicrystals undertaken by Ken Kelton, of Washington University in St. Louis, who worked with Dieter Herlach, of the Deutsches Zentrum für Luft- und Raumfahrt. But probably as important for the research community was the informal collaborative environment that grew out of the formal TEMPUS partnerships and extended beyond the flight of the facility.

Mike Robinson, currently the project scientist for the Microgravity Sciences Laboratory Electromagnetic Levitator (MSL-EML) and formerly the mission scientist for MSL–1 and the facility scientist for TEMPUS on IML–2, was instrumental in developing and solidifying the collaboration agreement between NASA and Germany for IML–2. He notes, "In the past, issues involving research with TEMPUS were resolved as a group decision. Because of the history of the TEMPUS group, we talk to [the hardware developers], and they take our opinions seriously. It took a number of years to establish that depth of trust, but once it was there, open collaboration followed quite naturally."

Rogers echoes that sentiment: "By MSL–1, researchers were taking the expertise they had in their own field and applying it to research being conducted by other scientists," explains Rogers. "There was a great synergy — everyone gained more information through these informal collaborations. In my opinion, this was the best thing to come out of TEMPUS. It led to the whole goal of the ISS, and was a neat way to demonstrate the power of the collaborative approach."



credit: NASA

It's over in a flash. A series of eight video frames from the IML–2 mission shows a deep-undercooled molten metal sample solidifying inside TEMPUS. In frames 3 through 6, the sample brightens as it goes through recalescence: the liquid suddenly solidifies and sheds a significant part of its heat as visible and infrared light as the now-slowed atoms and molecules cool down. The process takes a fraction of a second.

Containerless Processing Revisited

Indeed the containerless processing community took an international approach when it came to shaping and guiding plans for research and facilities on the International Space Station (ISS). The American, Canadian, German, and Japanese materials science research communities were brought together to look at the whole range of containerless processing and its potential for the ISS as a part of the Minerals, Metals, and Materials Society (TMS) meeting in March 1999.

The German researchers were included because of their electromagnetic levitator, TEMPUS; the Japanese for their Electrostatic Levitation Furnace, ELF; and the Canadians because of their acoustic sample-positioning device, known as Space-DRUMS™.

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World Space Congress: "The New Face of Space"

The World Space Congress (WSC) is a gathering of the Committee on Space Research (COSPAR), whose membership comprises scientific institutions, and the International Astronautical Federation (IAF), whose membership comprises largely engineers and technologists, along with the International Academy of Astronautics and the International Institute of Space Law.

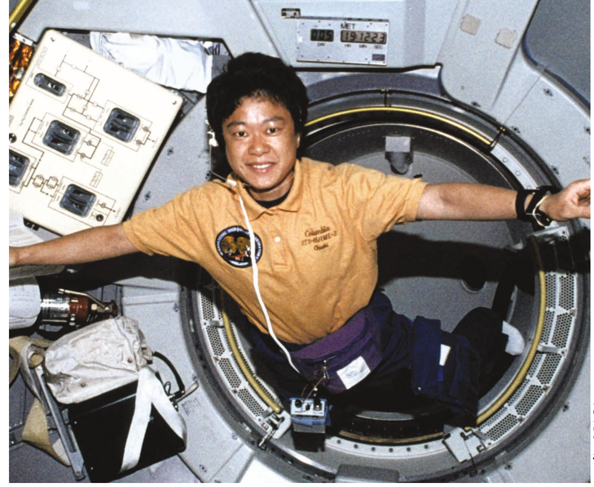
The first WSC was held in 1992 in Washington, D.C., and was sponsored by the National Academy of Sciences (NAS), a member of COSPAR. It was intended as a means of bringing together scientists, engineers, business executives, and government officials who have the common goals of getting humans and human-directed research safely into space to further the aims of all groups through cooperation and collaboration. In addition to bringing together space researchers, the congress serves as a platform to bring together nontraditional space industries that can benefit from the applications and innovations of space.

The second WSC is being held this year in Houston, Texas, October 10–19 with the theme "The New Face of Space." This congress is being sponsored by the American Institute of Aeronautics and Astronautics, which is a member of the IAF, under the auspices of the NAS.

NASA also has a role in the WSC, with a large exhibit at the conference and numerous education and outreach activities, including distance learning and participation in the Space Generation Summit, which is a gathering of 250 youths from around the world who will offer suggestions on how to "accelerate the pace of space" to the participants of the World Space Policy Summit at the WSC. Johnson Space Center is a supporting sponsor of the event, and more than 100 NASA principal investigators and employees will participate as speakers at the congress.

The congress has the following goals:

- Highlight synergies between space disciplines.
- Develop and strengthen international partnerships/relationships.
- Provide an environment for two-way dialogue between the providers, users, and integrators of space systems.
- Foster a vision of space-based applications to benefit humanity.
- Provide a platform to advance a common vision for the space community.



NASDA Payload Specialist Chiaki Mukai, the first female Japanese astronaut to fly into space twice, enters the Spacelab module to start a 12-hour shift performing experiments for the IML-2 mission.

credit: NASA

carrier to the Russian space station, *Mir*, during the first space shuttle-*Mir* docking mission in the Shuttle-*Mir* Program.

The Spacelab program enabled the international research community to learn how to cooperate on research of mutual interest and how to share and disseminate data. Perhaps the most important outcome of the Spacelab program, after the valuable scientific knowledge that was gained, was the foundation that was built for successfully integrating research on the International Space Station (ISS).

Says Bingham, "The fact that the Europeans were involved [in Spacelab] was a major factor in establishing the continuing validity of international cooperation for that kind of effort. It sparked a lot of interest on the part of the Europeans, especially for participating in any next step, so that when NASA began pursuing a space station in earnest in the early 1980s, there was international interest expressed to NASA."

Bridges Built

The invitation to make the space station an international venture also had support at a White House policy level. As Bingham notes, "In the early 1980s, when NASA was considering what a design [for the space station] would look like, international cooperation was mentioned, but it wasn't pitched to the president in that context. [President Ronald Reagan] added that element when he decided to build *Freedom* [the first iteration of what became the ISS]. So when he made the first announcement, he said he would do this with international partners."

The agreements to build an international space station were also made at this top level. Peter Ahlf, deputy division director for research integration within the Office of Biological and Physical Research (OBPR), explains, "First of all, there's an intergovernmental agreement, or IGA, which is signed at the State Department level. IGAs are multilateral, which means that all of the participating countries actually sign the agreement. In the case of the ISS, even the ESA member states that are participating individually each signed the agreement, along with the State Department and its equivalents on the Canadian, Japanese, and Russian sides. The current IGA governing development and construction of the ISS was signed by all participants on January 29, 1998.

"Below IGAs, we have memoranda of understanding (MOUs), which are the agreements between NASA and the cooperating international space agencies. These agreements specify major elements and the broad allocation of rights to those elements.

"At the science level," he continues, "we have different working groups that sit down and look at our mutual interests in science, and we have made separate agreements on how to cooperate at the [research] rack level."

Forging Partnerships

To ensure that participating countries have a fair chance of getting research on the station and that the research slated for the ISS is of the highest quality, two international working groups were created: the International Space Life Sciences Working Group (ISLSWG) and the International Microgravity Strategic Planning Group (IMSPG).

Says Ahlf, who sits on ISLSWG, "NASA has two representatives on each of these working groups. In the case of ISLSWG, the official agency membership includes Canada, Europe, Japan, Ukraine, and France and Germany, who are also member states of ESA. All the ISLSWG agencies have agreed to coordinate the research on the space station to maximize limited resources. So we all release research solicitations at the same time and we have a single common peer review in which an international panel reviews the proposals for scientific merit."

Once proposals have been received, the peer review panel looks at each proposal on its own merit. Only at the point of selection are commonalities in research identified. "So," notes Ahlf, "if we get to the point of selection, and Germany has a proposal that is a lot like one we [the United States] have, and both of them are deemed meritorious and we both want them selected, that's when we try to identify those commonalities and put together teams where it makes sense."

And while some investigators may wind up as co-investigators with an international counterpart, it's also possible that some experiments may be combined simply because they can use the same facility without interfering with one another "and it makes sense to do them together," says Ahlf. "But intellectually they are unique, and so there may be a team, but they're not really having to work together — the work is just being done in a coordinated way."

IMSPG was formed to coordinate the development and use of research apparatus among microgravity research programs in the physical sciences. Says Judee Robey, program development and coordination manager for the Physical Sciences Division of OBPR, "The big picture [for both working groups] is very similar — we talk about how we want to cooperate, but the details [of that cooperation] are different."

Like the working group for the life sciences, IMSPG uses International Announcements of Opportunity to allow the cooperating agencies to have a uniform means of soliciting research. Says Robey, "Unlike with the life sciences research, physical sciences research is highly dependent on instrument availability. The instrumentation and hardware facilities aren't as generic, so you may not be able to accommodate an investigation in existing facility hardware. So we select, through an international peer review panel, the highest-quality research first and then decide what hardware needs to be available for that research."

Agreements made under IMSPG are generally more specific and include specific investigations. "We generally don't draw up agreements until research

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credit: NASA

Crewmembers on STS-47 in the Spacelab module conduct experiments during the Spacelab J mission, which was dedicated solely to Japanese research.

The Walls Come Down *continued from page 11*

NASA participated because although the agency had no plans for supplying a levitator for the ISS, American researchers were interested in the possibility of using facilities provided by the other countries.

Robinson recalls the meeting's format: "During the first day, the hardware developers gave presentations on their facilities. The second day consisted of an open forum, during which researchers made suggestions about the best uses for containerless processing. The hardware developers learned a lot from the research community — future levitators will certainly reflect the results of that workshop."

In fact, Japan's plans for ELF were affected by that meeting. NASDA was planning to dedicate some of the racks in its ISS laboratory module to ELF, but design concerns and usability issues that were in part raised at the TMS meeting, as well as budget issues, have led the Japanese to postpone work on ELF in favor of pursuing other hardware options.

TEMPUS will be used on the ISS, although it will be altered and updated in response to researcher needs and will bear a new name. It is slated to go aboard the ISS in 2006. Robinson noted that TEMPUS was owned by the German space agency during its Spacelab years, but now negotiations are under way for ESA to take over the facility. Says Robinson, "The [ESA electromagnetic levitator, MSL-EML] is a very similar project [to TEMPUS] and uses much of the same hardware. The Germans are currently handling the facility upgrades."

A Different Drum

Space-DRUMS, or the Dynamically Responding Ultrasonic Matrix System, was also discussed at the 1999 meeting and is slated to be the first commercial standard rack–sized research facility aboard the ISS. Developed by Guigné Technologies Limited, of Newfoundland, Canada, the facility uses acoustics, or sound waves, to hold fluid or solid material samples in place in micro-gravity while they are being processed.

Space-DRUMS will provide opportunities for an entirely different kind of materials processing than the new version of TEMPUS. According to Frank Schowengerdt, director of the Colorado School of Mines Center for Commercial Applications of Combustion in Space (CCACS), CCACS has an agreement with Guigné to lease Space-DRUMS for combustion synthesis aboard the ISS, specifically to produce glass ceramics and porous ceramics in microgravity.

Says Schowengerdt, "Glass ceramics have never been made in microgravity. We expect to see big differences and advantages." Combustion synthesis, like the name implies, relies on high temperatures to create new materials. If those materials were to come into contact with the surface of a container during their development, then impurities could be introduced from the container walls.

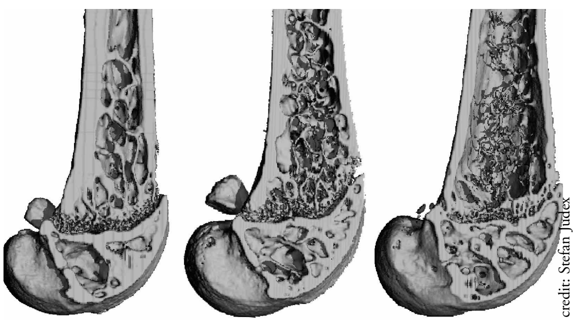
"[Jacques Guigné's] company was a pioneer in developing acoustic underwater imaging systems — his two main interests are acoustics and materials," explains Schowengerdt. "So when he and John Moore, a principal investigator here, connected, they got together and got talking about the need to do microgravity research in a totally containerless environment, and Guigné suggested acoustics."

Schowengerdt notes that Space-DRUMS can be used for research other than materials processing, and the Colorado School of Mines will not occupy the facility full-time, so Guigné will lease use of the facility to other research interests as well. NASA Principal Investigator Seth Putterman, of the University of California, Los Angeles, has been talking with Guigné about using the facility to study ripple turbulence created by acoustic radiation on a ball of water suspended in the device. Additionally, a group at NASA's Glenn Research Center would like to use the facility to study granular materials, specifically to determine what happens when glass beads are disturbed by acoustic radiation. An Italian investigator also hopes funding from his government to use

Shaken, Not Stirred: Mixing Vibrations With Genetics May Help Reduce Bone Loss for Astronauts

Astronauts may be able to lessen bone loss during spaceflight by standing on an oscillating platform for short periods. Ground-based tests have shown that genetics might indicate how bone will respond to this countermeasure.

Transitioning from a gravity environment to microgravity has long been known to cause upheavals in the body. Astronauts endure nausea, disorientation, a shift in body fluids, disruption of their sleep patterns, and other conditions as they adjust to near weightlessness and life in orbit. When they return to Earth, most of these conditions disappear, some immediately, some gradually. One condition, the loss of bone mass, can take several years to repair itself, and for some astronauts, the damage may be permanent. Astronauts lose bone mass much faster in space than they do on Earth, and as NASA looks ahead to longer spaceflights, scientists are searching for better ways to counteract this loss.



Genetics control 50 to 70 percent of the characteristics of bone. Above are mice bones of three different levels of density before treatment. Each strain was tested to see how it responded both to the mechanical stimulus of an oscillating platform and to disuse.

Bone loss is not an experience unique to astronauts; it is also a normal part of getting older. Once a person's skeleton has reached its peak bone mass, around age 30, it starts losing 1 to 2 percent of bone mass a decade. For women, this rate increases to 1 to 2 percent a year somewhere between three and eight years after menopause. While in microgravity, astronauts lose mass at the accelerated rate of 1 to 2 percent a *month*. When astronauts finally go to Mars, the round trip may take as long as three years. The astronauts might lose close to half their bone mass before they return, and approximately half of that loss could be permanent. In addition, the corresponding removal of calcium from bone raises the level of calcium in the blood, which increases the risk of kidney stones.

Bone Basics

Most people think of bone as a rigid, nonliving frame for the body, much like steel girders or concrete support beams. But bone is actually made up of both living tissue and a nonliving component comprising a protein matrix and minerals. Within the living tissue are cells that include osteoblasts (which are anabolic, or bone-forming) and osteoclasts (which are catabolic, or bone-eating). These two cell types work together, one eating, or resorbing, old bone back into the body, and the other replacing the old bone with fresh, new bone in response to the loads and stresses we experience during life. During spaceflight, the activity of osteoblasts slows down and the activity of osteoclasts may speed up, causing a net loss of bone density.

When humans lose bone density, some of what is lost is cortical bone, but mainly they lose trabecular bone. Cortical bone makes up the shaft of long bones such as the femur (thigh bone) and humerus (upper arm bone). Trabecular bone can be found next to joints at the ends of long bones, such as the femur ball that fits into the hip socket, and in vertebral bones. Any loss of density at such locations, where the skeleton experiences the most stress, significantly increases the risk of fractures, hence the large number of hip replacements among elderly people.

While the exact details of bone loss and restoration are still under investigation, scientists generally believe that when astronauts return to Earth, osteoclasts slow down while osteoblasts resume their normal activity level. In time, cortical bone returns to its normal density and strength. However, trabecular bone may not. Trabecular bone is organized like a lattice made up of rods and struts called trabeculae. During spaceflight, if trabecular bone loss results in a thinning of the trabeculae, the bone can be restored to its original strength. But if the trabeculae have been disrupted or destroyed, they cannot be repaired or replaced, and the bone is permanently weakened and vulnerable to fractures. This is what makes bone loss from long-term spaceflight so dangerous for astronauts.

Bone Loss in Space

Bone "adaptation" is a fairly straightforward process: bone responds to increases in muscular or mechanical stress by getting stronger, and responds to disuse (through spaceflight, bed rest, or immobilization) by getting weaker and losing density. For astronauts, the lack of gravity's effects and regular activity greatly reduces the stress on weight-bearing bones, and the bones respond accordingly by increasing the activity of bone-removing cells and reducing the activity of the bone-building cells. This explains in large part why astronauts lose bone mass in space. While in microgravity this is not a problem, but when astronauts return to Earth or land on Mars, their bones will no longer be able to handle the renewed stress caused by the body's resisting gravity. Astronauts try to counteract the loss of bone mass caused by microgravity by challenging their skeletons with vigorous exercise while in orbit. Unfortunately, while this exercise does help reduce muscle atrophy, it is extremely time-consuming and has not proven to be a strong enough countermeasure for bone loss.

Clinton Rubin, a principal investigator at the State University of New York (SUNY), Stony Brook, has been studying bone's response to mechanical and electrical stimuli (used by nerves to cause muscle contractions) for two decades. He believes that the body's lack of vigorous physical activity in space may not be the sole cause of the bone loss and muscle atrophy common during spaceflight.

Most scientists currently believe that bone mass is primarily controlled by the high-magnitude, low-frequency strain resulting from the mechanical loads on bones associated with vigorous exercise. Rubin and his associates, however, believe that a low-magnitude, high-frequency strain, such as that which the musculature continuously places on bones while a person is sitting or standing, may also have a great impact on bone morphology.

"The predominant stimulus that your skeleton experiences is not from running 100-yard dashes 20 times a day," explains Rubin. "The predominant stimulus is standing and sitting. So what is bombarding your skeleton essentially during all waking hours, during any weight-bearing activity, is a high-frequency, low-magnitude signal. This signal would, of course, diminish up in space because recruiting musculature to maintain posture is not a real problem."

Oscillating Platform Creates Stimulus

Having theorized that these low-magnitude, high-frequency signals strongly influence bone density, Rubin and his colleagues made a vibrating platform that reintroduces that type of stimulus to the skeleton. "How could I target the key sites within the weight-bearing skeleton? The way to target it is to make it bear weight," explains Rubin, and that's what his platform does. Test subjects stand on the platform — which has vibrations that are so low as to be almost undetectable to many — for 10 to 20 minutes a day. The oscillations "trick" the body into thinking it is receiving a load-bearing strain, and bones respond by getting stronger and stiffer.

This device has already been tested in several long-term studies with animals. One study, done on rats, compared bone densities of a control group to animals subjected to different conditions. All but the control group were prevented from regular, weight-bearing activities. One experimental group was exposed to 10 minutes a day on the platform, another was exposed to normal, weight-bearing activities for 10 minutes a day, and a third group had no stimulation of any sort. The platform group maintained their bone mass at similar levels to the control group, while the other two experimental groups lost significant amounts of bone. Another study, which lasted one year, compared a control group of sheep to a group that stood on the platform for 20 minutes a day. The platform group showed a 34 percent increase in the experimental group's levels of trabecular bone, and a 26 percent increase in strength, but no change in cortical bone levels. "So we found in this group of adult sheep that this noninvasive, low-level stimulus was strongly anabolic and produced bone that resulted in the bone being stiffer and stronger," describes Rubin.

credit: Cary Wolinsky/Trillium Studios

Persuading turkeys to stand on a vibrating platform for several minutes a day was only one of the many challenges facing Clinton Rubin in his research of the mechanisms of bone loss.

Several preliminary human trials have also been conducted on postmenopausal women and children with cerebral palsy. Both groups are at high risk of bone loss, one from aging and a reduction of hormones and the other through the lack of physical activity caused by their disease. The results have been positive and have shown minimal side effects.

These results, while still preliminary, show that the platform may be an effective countermeasure in space. Astronauts could stand on the platform a few minutes a day, even performing other tasks at the same time because the stimulus is so minimal. This treatment would be much less time-consuming than the several hours of exercise currently practiced and perhaps at least as effective as current pharmaceutical measures. Rubin is still working to determine the optimal parameters of magnitude and frequency that will produce the most effective results. Plans have just begun to try to fly this platform aboard a space shuttle mission so that the investigators can start testing it on humans in orbit.

Genetics Holds the Key

One of Rubin's colleagues at SUNY Stony Brook, Stefan Judex, is studying the response of bone to stimuli from a different angle. "We and others have found that there is a great variability in bone response [among individuals in test groups] when we subject either humans or animals to mechanical stimuli," says Judex. "Certainly since genetics accounts for a large part of the form and function of the skeleton, it's obviously the next step to look at how genetics affects the sensitivity of the skeleton to either mechanical stimuli or the removal of mechanical stimuli."

The characteristics of bone are determined by three factors: genetics, mechanical loading, and nutrition and hormones. Of these three, genetics accounts for 50 to 70 percent of bone properties such as bone mass and structure, and possibly how bones react to various stimuli. Judex is investigating this relationship of genetics both to bone mass and to the bone's response to mechanical stimulus and disuse.

To test his hypotheses, Judex selected three strains of mice with different initial bone densities (both trabecular and cortical) for his research. The low-density strain had a femoral bone mineral density (BMD) of 0.45 mg/mm^3, the mid-density strain had a BMD of 0.55 mg/mm^3, and the high-density strain had a BMD of 0.69 mg/mm^3. These strains were picked by their phenotype, or the physical characteristics of their bone density. Their genotype, or genetic makeup, controls the phenotype. Each strain was subjected to a mechanical stimulus (use of the oscillating platform) and to disuse (simulating either spaceflight or bed rest).

Unusual Results

Given that previous results from the oscillating platform have shown an unexpected degree of variability in humans, this experiment should have produced some indication as to its cause. The results were in fact rather unusual. For the low-density mice, the platform significantly increased bone formation rates, while disuse caused no change. For the mid-density mice, mechanical stimulation increased bone formation rates, and disuse significantly decreased them. For the high-density strain, neither stimulation nor disuse had any impact on bone formation rates.

These results appear to show that bone response to stimuli is determined by the

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Getting From Wild to Mild: Experiments May Lead to Ways of Neutralizing Virulent Microbes

Experts believe that as many as 4 million cases of food poisoning in the United States are caused annually by salmonella bacteria. The results of ground-based and in-space studies to learn about the ways bacteria multiply and conquer the immune system could lead to a better understanding of preventing or lessening the severity of bacterial infections.

credit: Tulane University

Cheryl Nickerson (at far right) works with her laboratory staff (from left to right): Carly LeBlanc, Rajee Ramamurthy, Kerstin Honer zu Bentrup, and Jim Wilson.

Spacefarers can remain in a closed system for weeks, sometimes months, and for proposed long-duration flights, maybe even years, breathing recycled air and drinking recycled water. Given that some virulent microbes appear to thrive in microgravity, that's not a promising scenario for health, according to Cheryl Nickerson, assistant professor of microbiology and immunology at Tulane University Health Sciences Center's program in molecular pathogenesis and immunity. Nickerson says that spacegoers already appear to have a higher risk of falling ill.

"Disease is related, first, to the host's immune status. The second part is microbial virulence, the ability of a microbe to cause disease," she explains. "When humans are in space, there appears to be some compromise to their immune systems. This suggests a higher risk of infection could occur in flight."

In ground-based studies simulating microgravity, Nickerson and her research team have found that a common strain of bacteria known as *Salmonella typhimurium* can alter its genetic profile, upping the production of certain self-protecting proteins that may enhance virulence. That could be unwelcome news for future astronauts. Given that microgravity may also reduce antibiotic effectiveness — because of an as-yet poorly defined interaction between the body and pharmaceutical measures, certain studies have suggested — and absent any new pharmacological approach, the difficult task of in-space treatment would be made even more challenging.

In the course of their investigation, Nickerson and her colleagues found that more than 100 salmonella genes, or about 3 percent of the salmonella genome, altered genetic expression. The changes made the bacteria far more lethal: mice injected with the strains grown in modeled microgravity died, on average, three days earlier than expected, from shock and from large-organ failure. At autopsy, Nickerson's research team found greater-than-anticipated numbers of the microbes within the livers and spleens of the experimental animals. "Clearly, there's something going on that is able to defeat the host's immune system," she says.

Nickerson's original studies in simulated microgravity involved the use of a device known as a rotating wall bioreactor, a vessel designed by NASA that mimics reduced gravity. Cells of *S. typhimurium* were placed in a culture within the bioreactor chamber. When the bioreactor spun, it maintained the cells in close approximation of freefall, which astronauts experience as up to one-millionth of Earth's normal gravity. The researchers also cultured *S. typhimurium* under normal-gravity conditions.

In addition, to study how *S. typhimurium* causes infection in people, Nickerson and her colleagues used the bioreactor to culture three-dimensional human intestinal epithelial cells, which more accurately model the physiology of human intestinal tissue than does conventional tissue culture. In response to the microbial invasion, the cells produced higher levels of substances called anti-inflammatory cytokines, which may help limit damage to the epithelial tissue following salmonella infection. The three-dimensional intestinal cells also showed less damage and cell death following salmonella infection as compared to other types of cells, known as monolayers. These observations are consistent with the self-limiting nature of salmonella infection, according to Nickerson, which can damage or kill epithelial cells in otherwise healthy individuals before being destroyed by immune reaction.

Treating and Neutralizing

The salmonella family of microbes that colonize uncooked or undercooked meat and poultry and nonpasteurized dairy products cause an estimated two to four million cases of gastrointestinal illness in the United States annually, costing up to $2 billion in yearly losses due to lost time at work and the need for medical treatments.

According to the Centers for Disease Control, salmonella-related maladies are among the most common intestinal infections in the United States, with 40,000 cases reported yearly. However, scientists estimate that because only 3 to 5 percent of salmonella cases are actually reported nationwide, and many milder cases are never diagnosed, the true incidence is much higher, likely in the millions. As many as 1,000 Americans die annually from salmonella infections.

Bacteria are not premeditated killers. Their goals, like all organisms, are to survive, thrive, and reproduce. To do so, they release certain proteins. In natural environments, these proteins neutralize substances harmful to the bacterium. When ingested into a human digestive tract, the same mechanisms are engaged. Although the strong acids found in the stomach kill up to 99 percent of the would-be bacterial colonizers, the 1 percent that do survive are able to "express," or release, the protective proteins that cause so much upset to their human hosts. The immunologic battle between host and pathogen can be fierce. Most of the time, the immune system wins, containing the infection, but sometimes the bacteria can overcome all defenses, and death can result.

Although most *S. typhimurium*–caused infections in the United States don't require hospitalization or serious medical intervention, at least in healthy people, they are potentially fatal if untreated in people with weakened immune systems (in developing countries, *S. typhimurium* is a leading cause of death, especially in children, due to dehydration). Deciphering the bacteria's molecular responses could lead — with new drugs and vaccines — to a means to treat or even neutralize salmonella infections, quickly lessening or eliminating the characteristic nausea, vomiting, intestinal inflammation, and diarrhea that they cause.

As humans work for longer periods in space, they may bring with them preexisting infections. Moreover, despite precautions, foods brought on board could conceivably harbor salmonella bacteria. Depending on severity, a salmonella-induced illness could pose serious dangers.

"We've all had it," Nickerson says. "You suffer for three to four days. You can't go to work. If you're on a space mission, it's even worse. Something like food poisoning could put a mission at risk, or in the worst case, threaten crew survival."

Drawing a Genetic Map

Because *S. typhimurium* is a well-known pathogen, investigation of the strain's genetic response to gravity's near absence could provide clues to infection protection from it or related microorganisms — perhaps even other, distantly related strains. "Salmonella is the best characterized of all the bacterial pathogens," Nickerson points out. "It's very closely related to *E[scherichia] coli*, which is the most commonly studied bacterium known.

"We're going to find out if spaceflight gives similar results to what we've found on the ground. We want to build a detailed molecular road map of how salmonella senses and responds to microgravity. It will be an incredibly complex map, but one we hope will guide us to effective remediation strategies." Nickerson should be able to draw a more complete map once results are in from a salmonella-virulence experiment that is scheduled to fly on an upcoming space shuttle mission.

Once on board, the experimental apparatus that contains the bacteria will pose no danger to the space shuttle crew. The experiment is entirely isolated from human contact and designed to easily withstand the rigors of takeoff and landing. The system is automated and will engage roughly one hour into the mission.

Eight test tubes made from a hardened plastic will be carried in a boxlike apparatus known as an isothermal containment module, or ICM. The tubes make up the Automated Group Activation Pack, or auto-GAP, which fits into the ICM. The auto-GAP uses a direct-current motor drive to autonomously start and stop experiments based on preprogrammed instructions. Each of the tubes allows controlled, sequential mixing of up to three fluids, which are isolated into three sections by rubber partitions, or septa. A bypass in the tubes permits fluid mixing in an adjacent chamber as plungers push the septa forward.

credit: Tulane University

Nickerson's research focuses on a well-known pathogen, *Salmonella typhimurium*, whose genetic response to gravity's near absence could provide clues to infection protection.

Three separated liquid media are contained within the tubes. One fluid will hold the bacteria, the second is a medium in which the bacteria will be grown and cultured, and the third is a fixing solution that essentially halts in place all biological activity, preserving the sample for later study. The entire apparatus is temperature-controlled so that bacteria will grow at 98.1ºF, or 37 ºC.

Just after launch, as the first plungers are engaged, the bacteria will be pushed into the second chambers' growth media. Two days later, after bacterial multiplication, the second plunger will engage, and all eight tubes will be fixed and ready for on-ground analysis once the shuttle lands. These samples will then be subjected to microarray analysis to analyze global changes in salmonella gene expression in response to spaceflight, as compared to on-ground controls.

"A dangerous thing in science is speculation about research you haven't yet conducted," says Nickerson. "I don't know what to expect. We do know what we've found on the ground. In space, we're dealing with a complete unknown. We're going to have to wait and see what the experiment tells us."

James Schultz

For more information about Nickerson's experiment, visit *http://www.synthecon.com/salmonella.shtml* on the World Wide Web. To learn more about the hardware that will house the experiment, visit *http://www.colorado.edu/engineering/BioServe/spaceflight.html*.

Meteorite Mystery

NASA researchers are studying the results of a microgravity experiment that has been 3.9 billion years in the making.

About 3.9 billion years ago, the birth of an asteroid in outer space set off what is probably the longest-running crystal growth experiment ever. Now NASA researchers are working to peer inside a piece of that asteroid to glean the results. The understanding they gain of the asteroid's composition and crystalline structure, which is unlike any scientists have yet had the chance to study, should

credit: Donald Gillies and Peter Engel

Image of a single slice of the Mundrabilla meteorite sample taken with computed tomography.

yield clues to how planetary bodies form and how to improve processing on Earth of important materials.

The focus of the work is the metallic core from an asteroid that eventually entered Earth's atmosphere thousands, if not millions, of years ago, judging from the weathering on the surface. The meteorite pieces that survived the trip landed in Western Australia. Small chunks were found in 1911, but in 1966 two multiton pieces were discovered and collectively dubbed the Mundrabilla meteorite after the area in which they were found.

The largest piece, weighing some 11 tons (9,980 kilograms), is still in Australia, but a smaller piece, roughly 6 tons (5,440 kilograms), was cut up and sent to various institutions for study. The Smithsonian Institution's National Museum of Natural History has several pieces, including one on exhibit and a 100-pound (45-kilogram) sample that is now on loan to Donald Gillies, discipline scientist for materials science at Marshall Space Flight Center's Microgravity Science and Applications Department.

Working with Peter Engel, an engineering specialist at Kennedy Space Center, Gillies is using a technique called computed tomography (CT) to study the internal structure of the meteorite piece. CT, known to most people for its use in medical applications, is most effective on objects composed of more than one type of material because it detects changes in density. Gillies says the materials in most meteorites are well-mixed, so CT would be ineffective on them, but the structure of the Mundrabilla meteorite includes distinct regions, or phases, of different materials. It is about 75 percent iron-nickel alloy and 25 percent iron sulfide, with the iron-nickel alloy forming a metal maze that runs through the iron sulfide. The metallic crystals that form the maze inside the meteorite are surprisingly large, and scientists have so far been baffled by how they could have formed the structure now seen.

Sulfur in asteroids is normally found between the metallic inner cores of the formations and their rocky outer parts. Usually the inner metal solidifies slowly, forcing out lighter, sulfur-rich liquid that can float away even under microgravity conditions if given enough time. For some reason, in the Mundrabilla meteorite, the metal's initial solidification was too rapid for the sulfur to float away. Estimates are that the meteorite must have initially cooled by 500ºC per year, a sprint in geological terms. However, researchers believe that the present structure of the iron-nickel regions may have formed by very slow cooling in astronomical terms, at a rate of about one degree per million years, perhaps much later than the rapid initial solidification. This is conceivable only if the asteroid were large enough to provide good insulation against cold space temperatures and the internal temperature was maintained by internal radioactivity. Yet the fast initial cooling would not have been possible with an insulating rocky surface. This is a paradox scientists find most puzzling.

Over the decades, very little of the meteorite's internal structure has been observed, because most techniques would require tearing apart irreplaceable samples. But using nondestructive CT, Gillies and Engel do not face that problem. Gillies says their work, the first real "look" inside the meteorite, could help solve the mystery of the meteorite's formation.

As many materials solidify, they form crystals, or patterned arrangements of atoms or molecules. The key question for Gillies is whether the crystalline structure of the metal maze in the meteorite has a dendritic structure, which means it grew in a treelike fashion, or has some other less common structure. "Are we looking at branches of it? Are we looking at leaves on branches of the dendrite?" asks Gillies. The researchers may even be able to spot a pattern in the metal branches that would not only point to the physical starting point of the original asteroid's crystal structure but would also give clues about its formation.

So far Gillies and Engel have not imaged enough of the meteorite chunk to say, but they are working toward a complete scan of the Smithsonian sample, which is over 2 feet long. Gillies says once the three-dimensional structure of the sample is revealed, it may allow him to confirm that the structure is indeed dendritic and in what direction it grew, or it could even point to some new, previously unrecognized mechanism for growth. In any case, just how the sulfide was trapped might become clear.

Most of Gillies's NASA research has focused on growing crystals in microgravity. In his experiments, he is usually setting up initial conditions to study how they influence the structure and properties of a material once it has solidified. For the meteorite analysis, Gillies must reverse his usual process, as he is looking at a completed crystal structure and trying to figure out what the initial conditions were that produced it.

One of the reasons Gillies was attracted to studying the meteorite is that, for the most part, its crystal structure likely formed in microgravity while the entire asteroid was orbiting in the asteroid belt. If that's the case, then the meteorite is really the longest-running microgravity experiment ever and could provide vital information about crystal formation that could not be obtained any other way. Gillies says learning about the meteorite and how it formed could lead to a better understanding of how other materials crystallize. For instance, the meteorite's large metallic crystals may have grown as a result of a process called coarsening, in which larger particles grow at the expense of smaller particles. Coarsening weakens materials over time, so understanding the process could prove helpful to industry.

Likewise, the formation of dendrites is fundamental to solidification theory, as most materials, particularly metals, begin

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credit: NASA

Peter Engel places an explosive mounting flange on the object positioning unit of the Kennedy Space Center computed tomography scanner. The flange, which is used to attach solid rocket boosters to the shuttle, was checked for cracks before use on a launch.

Computed Tomography

Computed tomography (CT) was first used decades ago as a medical tool, but it has long since been put to use imaging everything from engine parts to meteorites. The technique allows researchers to create an image of any object that has density changes within it. That includes objects made of more than one material, objects made of a single material of nonuniform density, or objects that have air pockets inside them.

Computed tomography does not, in fact, take the best possible image of an object's insides, but better techniques require destruction of the object. When dealing with human brains, space shuttle parts, or a host of other things that perform better intact, CT is a welcome alternative.

The idea behind computed tomography is to create a picture of a very thin cross section of an object by passing a very thin fan of X-rays or gamma rays through it and then repeating the process until every slice of an object is imaged in order to create a three-dimensional representation of the object. Researchers Donald Gillies and Peter Engel are conducting the meteorite CT work at a Kennedy Space Center facility using gamma rays given off by a piece of radioactive cobalt, about the length and diameter of a pencil lead, as it decays.

The cobalt is shielded by 700 pounds (318 kilograms) of depleted, nonradioactive uranium. During imaging, a narrow slit in the container is opened automatically, and the cobalt is positioned in back of it so the gamma rays can be emitted.

About 6 feet away is a line of 125 detectors, parallel to the floor and spaced just under half an inch (10 mm) apart, that detect the incoming gamma rays. Samples are placed between these detectors and the gamma ray or X-ray source. CT imaging is possible because denser materials reduce the number of rays more than less dense materials. For CT using the cobalt source, this is due to a phenomenon known as Compton scattering.

Compton scattering generally occurs when the gamma ray photons, which like visible light are forms of electromagnetic radiation but vibrate much faster, are scattered by the electrons around atoms. This prevents some from reaching the detectors and, hence, reduces the signal ultimately detected. The atoms of denser materials have more electrons, so they cause relatively more scattering and weaker signals.

The full imaging process begins with the measurement of the gamma rays through air, which causes almost no scattering. Then the object to be imaged is moved in front of the gamma ray source and the detectors take measurements that are compared to air readings. This produces one detector data set relative to the density of the material in the path of the rays, but not enough to get a complete image of the cross section.

Getting a full and accurate image depends on determining the density of each specific point on the imaged slice. One way to do that is to move the object back and forth in front of the gamma rays and rotate it to various angles. Ultimately the CT scanner takes about a million or so readings. The density of a specific point is determined by mathematically comparing the many detector readings of gamma rays that went through that point from different angles with the rays sent through the air. Then each point on the slice can be put together, or mapped, to create a picture of the slice.

"A good analogy might be if you sawed a tree trunk in half, gathered up all the sawdust, and were able to put all the sawdust grains back together the way they were before," says Engel, who serves as head of the Kennedy Space Center CT facility. "Those sawdust grains would make you a flat, two-dimensional picture of that particular cross section of the tree trunk," he explains.

The CT images created can show even minute differences in densities of materials, so the CT slice pictures reveal everything from the internal structure of a piece of equipment, to defects on its surfaces, to cracks, which show up because of air or foreign substances in the crack. Multiple slice images can be stacked digitally on top of each other to create a computerized three-dimensional image of the object. Besides peering into the Mundrabilla meteorite, Engel uses CT to examine various shuttle components for defects, as well as for numerous other applications.

A Zeal for Zeolites

Growing zeolite crystals in space may show how nature makes some of its tiniest traps and help researchers learn how to grow better crystals for a multitude of uses on Earth.

Chances are, if you've ever washed a load of clothing, you've used zeolites. Zeolites, rigid crystals of silicate minerals with a honeycomb-like structure that has certain ions loosely attached to the framework, are often used in laundry detergents. They exchange magnesium and calcium ions from mineral-rich "hard" water with their own sodium ions, thereby greatly improving the sudsing effect of the soap. In addition to this ion-exchanging ability, the structure of the zeolites allows them in other situations to filter substances by excluding larger molecules while allowing smaller molecules to pass through, or to act as catalysts for chemical reactions to take place within the internal cavities of the zeolite crystals.

Learning more about the structure of these versatile, useful crystals is the goal of Principal Investigator Al Sacco Jr., of the Center for Advanced Microgravity Materials Processing (CAMMP) at Northeastern University in Boston, Massachusetts. By studying zeolite crystals grown in space, Sacco hopes to find out how the crystals may be processed synthetically to work more effectively in numerous current applications on Earth and in new applications, such as in storing hydrogen for use as a fuel.

Nature's Little Traps

Zeolites are made up of the elements silicon, aluminum, and oxygen. The crystals consist of alternating arrays of silica (beach sand, SiO_2) and alumina (aluminum oxide, Al_2O_3) and can take on many geometric forms such as cubes and tetrahedrons. The crystals can be found in volcanic and sedimentary rocks in arid regions, and on the seafloor. There are nearly 50 different types of naturally occurring zeolites (hypothesized to be 20 percent of the total possible number of structures), and they vary in crystallographic structure, molecular pore size, and chemical composition, among other aspects. Variations can also occur among zeolites of the same group, due to the different environmental conditions under which a particular zeolite crystal was grown. Impurities in the environment, for instance, can affect how a zeolite crystal forms, and the same structure can have varying ratios of silicon to aluminum.

Zeolites have a rigid crystalline structure with a network of interconnected tunnels and cages. The silica and alumina, two types of tetrahedral atomic groups, link to form complex, three-dimensional networks, with molecules of water (H_2O) and ions of minerals such as sodium (Na) and calcium (Ca) housed in the cavities of the framework. The ions can be readily exchanged for ions of other types of minerals when in an aqueous solution, such as when sodium is exchanged for the magnesium and calcium in laundry water.

The cavities in zeolites are often a place for catalysis, in which the zeolite speeds up the conversion of one chemical into another without being affected or consumed by the reaction. "They are like molecular sponges," says Sacco. "They're very porous and they only allow molecules in that are a certain size. The active sites within convert these to a different molecule."

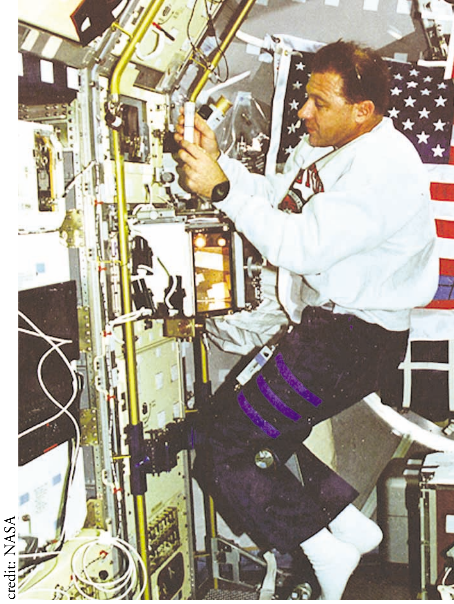
The special structure of zeolites also makes them quite useful as filters. Their small pores can sift out pollutants in water and air, and the crystals are commonly used to trap odor-causing molecules, to separate chemicals, and to adsorb gases. This filtering action enables chemists to manipulate molecules and process them individually. Because of their chambered structure, zeolites can act as tiny storage tanks as well, holding fluids, such as hydrogen, until the crystals are heated. As the crystals warm up, their framework expands, and molecules of fluid held within the chambers of the crystals can be driven off. In fact, the name "zeolite" comes from the Greek words *zeo* (to boil) and *lithos* (stone), meaning "the rock that boils." The fluid can then be recaptured when the zeolite cools.

Catch and Release

The latter two characteristics of zeolites, their ability to store and release fluids, especially interest Sacco. To better understand the special characteristics of zeolites, Sacco has been studying synthetic versions of them in his laboratory at CAMMP, one of the commercial space centers in the Space Product Development Division of NASA's Office of Biological and Physical Research. Crystals grown on Earth typically are only 2 to 8 microns in width. "That's about one-tenth the thickness of the human hair," says Sacco — much too small to accurately determine their structure. They're tiny because when zeolites nucleate (form) from a water solution, their density, which is twice that of water, causes them to sink to the bottom of an autoclave, the special container in which they are grown. This sedimentation causes the crystals to leave the nutrient-rich solution and to fall on top of each other, often merging to produce a large number of small, intergrown zeolite crystals instead of larger, separate crystals.

Sacco needed larger crystals to determine their structure, and he suspected that larger crystals could be grown in microgravity, where the effects of gravity, such as sedimentation, are minimized. This proved to be the case when he sent his zeolite crystal growth experiment to be conducted on missions STS-50, in 1992; STS-57, in 1993; and STS-73 in 1995, a mission on which he flew as the payload specialist operating the experiment. Improving hardware for each successive flight made it possible to grow crystals that were at least 200 times the size of crystals grown on Earth and of better quality. "In microgravity, materials come together more slowly, allowing zeolite crystals to form larger and with better order," says Sacco. He hopes to learn more about the physical and chemical mechanisms for zeolite nucleation to be able to better control nucleation on Earth. Understanding nucleation also may help him to determine how to control the location of aluminum atoms within the silica framework to affect the solid acid properties of zeo-type materials used in the

Principal Investigator Al Sacco flew as the payload specialist operating his own Zeolite Crystal Growth (ZCG) experiment onboard STS-73 in 1995. What he has learned from this and subsequent flights of ZCG could improve zeolite materials for a variety of purposes, from chemical processing to fuel storage.

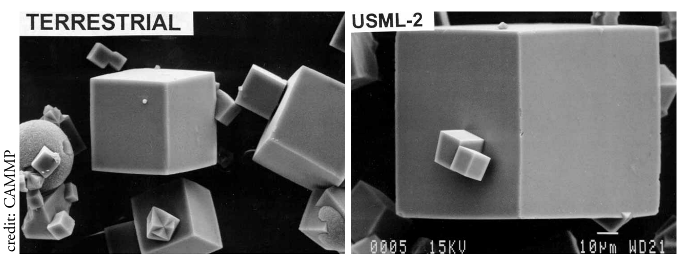


credit: NASA

petrochemical industries, and to better determine locations for cations, the materials that can be used to block the pores of zeolites.

The zeolite crystal growth experiment will fly with advanced hardware on STS-107, scheduled for launch in late 2002/early 2003. The hardware consists of sample tubes that hold the components that form zeolites and the Zeolite Crystal Growth Furnace, a furnace unit used to process the samples. The mixing protocol will vary with each sample to optimize the formation of only the desired zeolite — not others of less industrial interest. Finding the right mix requires that these solutions, which begin to react on contact, are uniform in concentration across the sample tube volume. Once mixing is complete, the samples will then be placed in the furnace for automated processing. The samples, which Sacco hopes will include crystals up to 1,000 times their normal size on Earth, will be examined after their return from orbit.

Zeolite crystals also are being grown on the International Space Station (ISS). Conducting zeolite experiments on the ISS allows crystals to grow for longer periods, resulting in even larger and more structurally perfect crystals. This will make it easier for scientists to study the internal structure of different types of zeolites. The space station also will allow scientists to study results and repeat experiments, modifying experiment conditions to improve the quality of crystals, which is the same iterative process used when conducting investigations in ground-based laboratories.



credit: CAMMP

Zeolites grown on Earth range in size from 2 to 8 microns (left). In microgravity, the crystals can grow to at least 200 times this size, allowing researchers a better view of their unique structure.

The hardware for these studies on the ISS, the Improved Zeolite Electronic Control System (IZECS), was flown to the ISS on STS-108 in December 2001. This advanced hardware includes a set of 19 Teflon-lined aluminum or titanium autoclaves that fit inside the furnace. Inside each autoclave, a motor will mix the two solutions according to procedure and protocol commands sent by scientists working on the ground in the CAMMP remote operations center. The earthbound scientists also issue computer commands to the furnace to heat the samples.

The first set of samples for processing in the IZECS was carried to the space station on STS-110 in April 2002. Although a back-up system failed, the primary control system was able to process the samples. The first set of samples for postflight analysis was returned to Earth on STS-111 in June 2002. To date, half of the samples have been analyzed, and scientists have found crystals that are larger and of slightly better morphology than their Earth-grown counterparts. However, indications are that a number of samples were not mixed to completion. The reason for this inadequate mixing is being determined.

Applications on Earth

The work that Sacco and his team are doing could help them learn how to control zeolite structure to make them more effective miniature sieves, traps, and storage tanks. Zeolites form the backbone of industrial chemical processing. Sacco says, "Zeolites are now *the* most used material for catalysis in the chemical processing industry," and virtually all the world's gasoline is produced or upgraded using zeolites as catalysts in the refining process. Zeolites break up large, heavy oil molecules, making them smaller, and add hydrogen to the structure of the oil molecules so they burn more effectively. This function is related to the distribution of the aluminum atoms within the silica framework and is critical to improving the amount of these molecules that can be "upgraded." Industry wants to improve zeolite crystals so that more gasoline can be produced from a barrel of oil, making the industry more efficient and thus reducing America's dependence on foreign oil.

"Fine-tuning the structure of the zeolites to get more gasoline out of a barrel of oil during the refining process by as little as 1 percent would result in a $400 million [positive] swing in our [national] balance of payments," says Sacco. Zeolite improvements also can be applied to detergents, optical cables, gas and vapor detection, environmental monitoring and control, and chemical production techniques that reduce hazardous by-products.

In the future, zeolites may even be used for storing new fuels that are cheaper and cleaner. Hydrogen is one candidate fuel that might be stored and transported efficiently using zeolites. Sacco explains, "The problem with hydrogen storage is that it requires very cold temperatures, to make it liquid for storage, or very high pressures." Zeolites could be used to adsorb hydrogen at close to ambient conditions and then, after being heated ever so slightly, allow the hydrogen to escape. Cation material added to the zeolites would block the tiny holes in the porous zeolites, allowing the hydrogen to be stored. "These materials act just like caps on an ink bottle," says Sacco. "We heat them up and they move away from the porous area. We fill the area with hydrogen, drop the temperature a tenth of a degree, and they slide back in place and seal off the hydrogen." If zeolites do work for storing hydrogen, humans would be that much closer to using the most abundant element in the universe as a pollution-free fuel, lessening the dependence on petroleum.

Sacco dreams of returning to space to serve as a mission specialist on the ISS conducting continuous experiments on materials of interest to the petroleum and other industries as well as to researchers. He explains the value of this unique laboratory: "The ISS for the first time allows scientists and engineers a functioning laboratory to do investigations and exploratory science in the way it must be performed, with hypothesis and deduction, followed by observation and analysis. Researchers can perform their investigations the way they have been trained, learning

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Raiding the Cosmic Pantry

Among the most common questions people have about spaceflight are what kinds of foods do astronauts eat, and how do they eat them in orbit. Through the Space Food Systems Laboratory at the Johnson Space Center and the Food Technology Commercial Space Center at Iowa State University, NASA's Office of Biological and Physical Research has a hand in serving up the answers for public consumption.

In space, the view is spectacular to go along with a good meal, but without the convenience of a local grocery store or a place that will deliver pizza, whatever is in the pantry aboard the International Space Station (ISS) is what's for dinner.

Fortunately for crewmembers, the pantry is well-stocked during missions. Due to American and Russian astronauts sharing living space aboard the ISS, NASA provides half the food supply, and the Russian Space Agency furnishes the other half. Entrees such as beefsteak, chicken teriyaki, scrambled eggs, and beef stroganoff with noodles make up the NASA menu, while the Russian ration includes chicken and rice, fish, ham omelets, and prune omelets. Both menus also feature an assortment of fruits, vegetables, and snacks.

credit: NASA

Commander Yury Usachev (middle) and Flight Engineers Susan Helms and Jim Voss hang around the dinner table with drinking straws in hand in the *Zvezda* Service Module during the Expedition 2 mission aboard the ISS in 2001.

The groceries from each country arrive at the station on separate pallets but are stored inside the same cabinet, which is located in the Zvezda Service Module, where the station's galley is located. The Russian Space Agency primarily uses cans to preserve its food; NASA uses flexible foil packaging to maintain food preservation and to help trash compaction. American food stored on the ISS is prepared at the Space Food Systems Laboratory at Johnson Space Center in Houston, Texas. Food prepared for the station must be able to stay stable at room temperature for nine to 12 months, because there is no refrigerator or freezer on the station. It would take a lot of power to keep a refrigerator running.

The space dining experience has improved immensely since the earliest crewed flight missions. On *Mercury*'s first flight to orbit in 1962, astronaut John Glenn found eating fairly easy, but the menu was limited to bite-size cubes of gelatin-coated food, freeze-dried powder, and semi-liquids in aluminum tubes. By the time the Gemini missions took place in the mid-1960s, improved packaging boosted the quality of foods. Gemini astronauts enjoyed selections such as shrimp cocktail, chicken and vegetables, and butterscotch pudding. The Apollo program not only put a man on the Moon but also put hot water inside the spacecraft, which made rehydrating foods easier. On the space shuttle and the ISS, crews prepare food much as they might a prepackaged convenience meal at home — minus the microwave. Each astronaut opens a food package; adds water if needed at the rehydration station; pops it in the forced-air convection oven, which takes about 20 minutes to reheat food items due to low power input; and finally consumes the meal using regular utensils on a tray attached to his or her lap.

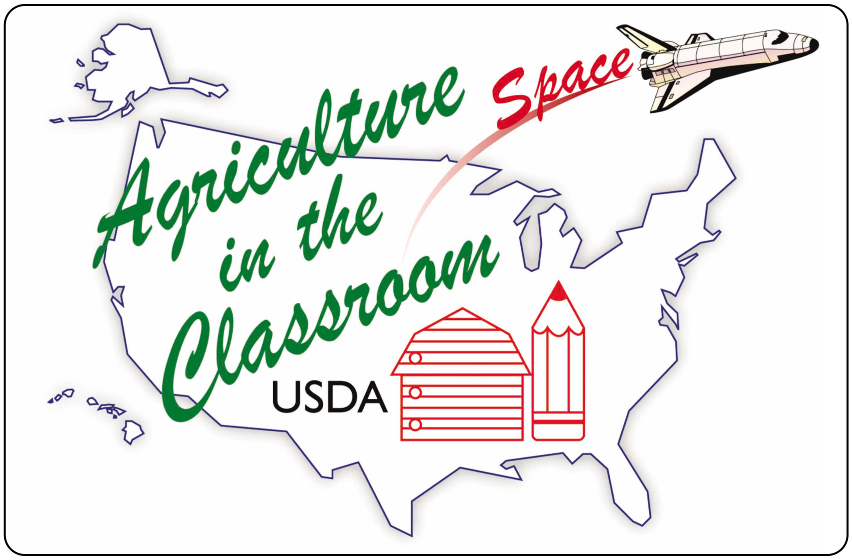
But even with the improvements in space fare, there are still some challenges to dining in orbit. As soon as crewmembers enter the microgravity environment, they experience a fluid shift. Some of the fluid normally in the lower body shifts to the upper body, leaving the crewmembers with a slight congested feeling. This affects the way foods taste in much the same way having a cold does. To make up for this, crewmembers often douse their food with hot sauce and ketchup to liven up the flavor.

"We see this happening a lot on the space shuttle," says Vickie Kloeris, subsystem manager for space shuttle and space station food at the Johnson Space Center, "but on ISS what we're seeing more is the crewmembers want to add condiments to relieve some of the boredom with the food."

Limited food selection is a challenge. It is difficult to supply enough variety for a whole ISS mission increment, as Flight Engineer Jim Voss discovered firsthand. "I enjoyed all the food during the five and a half months I was there," says Voss. "The Russian au gratin potatoes were especially good, but the menu did get old after about four months of eating menus on an eight-day rotation."

To help break up the monotony, there are usually two space shuttle visits that deliver a bonus container about the size of a lunchbox filled with items not included in the baseline menu such as candy, cookies, preferred store-bought items, and fresh fruit.

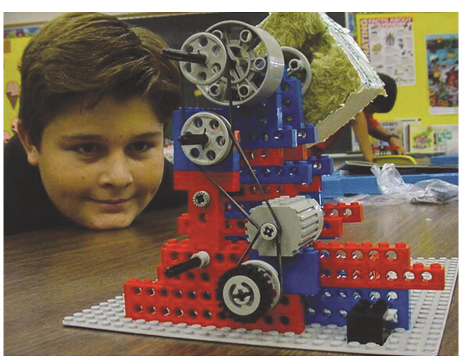
A future goal for ISS menu planning is to provide appropriate ethnic foods for crewmembers of varying nationalities and religious beliefs. Among the active payload specialists and career astronauts, 40 are from countries other than the United States and Russia, and their home cuisines are not represented in current ISS selections. For now, says Charles Bourland, former manager of the Space Food System Laboratory, international crewmembers



credit: SAITC

usually bring a few food items from their own countries as token samples. This also holds true for American astronaut Ed Lu, who will take some Asian dishes when he embarks on Expedition 7 to the ISS, slated for launch in early 2003. As for Payload Specialist Ilan Ramon, an STS-107 astronaut from Israel, his token samples will be kosher, or ritually fit for use according to Jewish law (not all of Ramon's food will be kosher, but his menu selections were chosen using kosher guidelines). Ramon's kosher food is commercially purchased. "All we do is wash the pouch, put a label on it, and stow it in the tray," Kloeris says.

This tradition is likely to continue to accommodate crewmembers not from the United States or Russia, and alternative solutions to providing a taste of home may be on the horizon. The National Space Development Agency of Japan (NASDA) has expressed interest to NASA in providing a portion of the food supply for Japanese crewmembers aboard the ISS.



credit: SAITC

Pleased at his masterpiece, sixth-grader Jared Campbell, of Dr. W. J. Creel Elementary School in Melbourne, Florida, watches his clinostat made of Legos and a battery-powered motor whir and turn a rockwool cube, a block of super-dense material resembling fiberglass insulation commonly used as a soil substitute. Ann Donald, Campbell's teacher, was a 2001 Florida Agriculture in the Classroom Teacher of the Year.

For a variety of educational materials about astronaut chow, including mock space shuttle food trays, posters, and videos, visit the Food Technology Commercial Space Center (FTCSC) web site at *http://www.ag.iastate.edu/centers/ftcsc/*. The FTCSC is an OBPR-funded communication center that encourages faculty and commercial involvement with long-term space food research. Through workshops, student contests, and outreach, the FTCSC not only brings more minds to the table, but also enriches public awareness about space research.

For information about school group tours of the Space Food System Laboratory at Johnson Space Center, contact Vickie Kloeris, lab manager and technical monitor for the FTCSC, by phone at (281) 483-3634 or by e-mail at *vickie.l.kloeris1@jsc.nasa.gov*.

Educational Space Programs Now Available

The **Eco-Lab Space Program** provides students in the fifth through eighth grades with activities in the areas of food processing and nutrition, waste management and resource recovery, and plant production. Along with learning active research methods using science and math, students gain an understanding of relationships among humans, plants, food, and waste recycling. (*http://www.eco-lab.org*)

BioBLAST (Bio — Better Learning Through Adventure, Simulation, and Telecommunications) is a multimedia supplement for high school biology classes that presents adventure missions involving the interdependent components of a bio-regenerative life-support system (BLISS) for long-term space habitation. Based on NASA's Advanced Life Support Research program, the students take charge at a virtual lunar research station, where they can test their own BLISS designs. (*http://cotf.edu/BioBLAST/main.html*)

The **Farming in Space** activity provides a unique learning experience for teachers and students because it relates to an investigation on the ISS called Biomass Production System 24-Day Test. Students in grades K–12 use the same kind of seeds used on the station to grow specimens in their classrooms. Teachers and students can examine a number of basic principles in plant biology and crop production through hands-on experiments using a simulated Biomass Production System, a growth chamber designed to grow plants on the ISS. (*http://voyager.cet.edu/iss/activities/farminspace.asp*)

Plowing Space in the Classroom

A new NASA-USDA program will reach more students to sow the seeds of interest in space farming.

While stocking the International Space Station with enough food, oxygen, and water for six-month stays has been manageable, supplying a crew with the essentials for an extended mission to the Moon, Mars, or some other more distant celestial depot would be impractical if not impossible. Since a continual resupply of basic life support elements is not an option, NASA has considered sending plants on longer missions to provide food, regenerate oxygen, and contribute to water purification processes.

To raise student awareness about the critical role plants will have in the future of space exploration, NASA and the United States Department of Agriculture (USDA) have created a program called Space Agriculture in the Classroom (SAITC). This program will expand the distribution of educational material provided by several non-profit organizations to a broader audience.

The cosponsored program is nourished through a patchwork of partners, including the USDA Cooperative State Research Extension and Education Service and NASA's Office of Biological and Physical Research. The relationship between the partners and the program is mutually beneficial, since most partners already have outreach services.

Though SAITC is still developing, the program currently provides science teachers with bilingual (Spanish and

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RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Research Opportunities in Physical Sciences

The Physical Sciences Division now issues only one NASA Research Announcement (NRA) a year, with information for proposing to each research program included. One proposal date remains for 2002:

Fluid Physics: NRA-01-OBPR-08-D opened September 2, 2002, with proposals due December 2, 2002. The NRA seeks research that explores fundamental physics and the dynamics of simple and complex fluids.

Further information on this announcement can be found on the World Wide Web (WWW) at *http://research.hq.nasa.gov/code_u/nra/ current/NRA-01-OBPR-08/index.html*.

Joint National Cancer Institute/NASA Solicitation

The National Cancer Institute and NASA are soliciting projects through a Broad Agency Agreement (N01-CO-27042-32) titled "Fundamental Technologies for the Development of Biomolecular Sensors." Research will be geared toward the development of technology that can measure, analyze, and manipulate molecular processes in vivo. The deadline for applications is November 1, 2002. For more information, download the announcement from *http://rcb.cancer.gov/rcb-internet/appl/rfp/27042/toc.pdf* on the WWW.

Research Opportunity in Bioastronautics

The Bioastronautics Division is soliciting proposals for the ground-based study of space radiation biology and space radiation shielding materials. This announcement (NRA-02-OBPR-02), proposals for which are due on November 25, 2002, is seeking research that will use beams of high-energy heavy nuclei to simulate the components of galactic cosmic rays. These rays are considered the most biologically significant component of space radiation. More information about this announcement can be found at *http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-02/index.html* on the WWW.

TECHNICAL MEETINGS

2002 Fall Meeting — The Minerals, Metals, & Materials Society

Columbus, Ohio
October 6–10, 2002
http://www.tms.org/Meetings/Fall2002/Fall2002.html

October's meeting of the Minerals, Metals, and Materials Society will focus on physical metallurgy and materials and will include a variety of technical symposia. Activities include a poster session and approximately 100 technical sessions that will focus on new research into materials processes, analysis techniques, and equipment advances. As an additional convenience for attendees, the meeting is being held in the same location as the American Society for Metals International's Materials Solutions Conference.

World Space Congress 2002

Houston, Texas
October 10–19, 2002
http://www.aiaa.org/wsc2002/

The theme for this year's meeting is "The New Face of Space." The World Space Congress is a joint gathering of the International Astronautical Federation, the International Academy of Astronautics, the International Associates of Space Law, and the Committee on Space Research. Scheduled events include more than 16 plenary sessions with such themes as space commercial applications, life sciences and biomedicine, and the vision for the next 25 years of scientific investigations in space.

41st AIAA Aerospace Sciences Meeting and Exhibit

Reno, Nevada
January 6–9, 2003
http://www.aiaa.org/calendar/index.hfm?cal=5&luMeetingid=582

The American Institute of Aeronautics and Astronautics (AIAA) will gather in time to celebrate the 100th anniversary of powered flight and the subsequent birth of the aerospace industry. Papers and session topics include aeroacoustics, air breathing propulsion, astrobiology/space biology, propellants and combustion, and thermophysics. There will also be a series of sessions that trace the evolution of Earth-based flight and spaceflight through-

PROGRAM RESOURCES

General Site

Office of Biological and Physical Research (OBPR)
http://spaceresearch.nasa.gov

- Latest biological and physical research news
- Research on the International Space Station
- Articles on research activities
- Space commercialization
- Educational resources

Descriptions of Funded Research Projects

Science Program Projects
http://research.hq.nasa.gov/taskbook.cfm

Commercial Projects (also includes a description of the Commercial Space Center Program and other information)
http://cscsourcebook.nasa.gov

Space Life Sciences Research Resources (for literature searches)
http://spaceline.usuhs.mil/home/newsearch.html

Zeolite *continued from page 21*

from mistakes and pushing the limits of the freefall environment of low Earth orbit."

Julie Moberly

Information in this article was taken from the following sources: CAMMP. *Center for Advanced Microgravity Materials Processing.* (n.d.). Retrieved August 9, 2002, from *http://www.dac.neu.edu/cammp/CAMMP_description.htm* "It's a Filter, It's a Sponge: Zeolite Crystal Growth." (2002). NASA fact sheet #FS-2002-06-096-MSFC. Price, Steve. (2002). "Hydrogen in a Bottle" prepared for *Science@NASA. Zeolite Crystal Growth Furnace.* (n.d.). Retrieved August 9, 2002, from *http://spaceresearch.nasa.gov/research_projects/ros/zcg.html* "Zeolite Crystal Growth Furnace." (2001). NASA online fact sheet #FS-2001-11-194-MSFC. Retrieved August 9, 2002, from *http://www.msfc.nasa.gov/NEWSROOM/ background/facts/zeolites.html*

Feature *continued from page 13*

has been selected, and then we get together with our partners to decide who will provide what hardware," Robey adds. "But once all of the hardware is on orbit, then our process will become more like the life sciences process. We will solicit research that works with the available hardware, or other types of research, if resources are available to develop new hardware."

Robey also points out that the collaboration process for getting research on the ISS is somewhat different than it was for Spacelab. With Spacelab, the United States had a commodity — space shuttle flights — that it could trade for the use of international research facilities. Because the ISS is "internationally owned," there is more of a trade-off with respect to research utilization and the use of available facilities. Getting the most benefit from the research and the facilities drives the collaborative choices made by the various ISS partners. "On the ISS, we are trying to get researchers to collaborate at the grass-roots level or on the ground to address research questions so that each investigation adds something to the overall flight experiment result," comments Robey.

Research sponsored by the Space Product Development Division follows a different process. The commercial development researchers have an international consulting group to aid with research collaboration. The businesses that have developed hardware for space research discuss the sharing of instruments with international partners, and they also make commercial facilities available to noncommercial researchers.

credit: NASA

As the research opportunities that are available on the ISS are fully realized, people can look back on the legacy of Spacelab and reaffirm that space truly is an international arena. Astronauts looking at Earth from the ISS don't see international boundaries — they see a planet without borders.

The Next Generation

In addition to the working groups that ensure that only world-class research will be conducted aboard the ISS, the space research community sponsors and participates in many other venues for forging relationships that can lead to collaborations. Scientific meetings serve as a primary means for sharing results and progress of investigations and ferreting out others with similar interests. These conferences and symposia, which take place all over the world, range in focus from the broadest themes of the future of space research and exploration to specialized research and engineering topics.

The World Space Congress (see sidebar, p. 12) brings those involved in space research and exploration together on a grand scale. The congress, held once every 10 years, attracts international researchers from the space sciences, engineering, and technical fields, as well as from the business sector, to communicate about the future of research and humans in space and the means to accomplish research and engineering goals.

Although the World Space Congress is sponsored by large international organizations, smaller-scale meetings as a means for developing collaborative research also abound and take place on a more frequent schedule. The annual meetings of the Japan–United States Technology and Space Applications Program (JUSTSAP) are an example of international cooperation on the smaller scale. American and Japanese scientists who are interested in microgravity research participate in JUSTSAP in order to identify similar research goals and to spark new inquiries. Several joint research proposals have gone to both NASA and NASDA as a result of connections made through JUSTSAP.

Through the collaborative efforts — formal and informal, large and small, in orbit and on the ground — of the Spacelab decades, the future of space research and exploration is now securely anchored in international cooperation. Historian Bingham remarks, "It's sort of axiomatic that anything you do in space has got to be international. You know, you don't even talk about going to Mars anymore without making it a potential international venture."

And so, as people move toward fully realizing the research opportunities afforded by the ISS and look ahead to the next generation of hardware development and research to be conducted, they can look back on the earliest cooperative efforts, like Spacelab, and reaffirm that space truly is an international arena. Says Bingham, "Humankind gets up there and doesn't see borders — you don't see anything but the whole Earth."

Julie K. Poudrier

For more about ISS partner space agencies and their history of cooperation with NASA, see the series of articles published in *Microgravity News* and available online."The European Space Agency: Introducing an Old Friend" *http://mgnews.msfc.nasa.gov/fall98/esa.html,* "Japan: A Key Contributor to the ISS" *http://mgnews.msfc.nasa.gov/winter98/japan.html,* "International Cooperation on the ISS: A Focus on Canada" *http://mgnews.msfc.nasa.gov/Summer99/CooperationontheISS.html, and* "The NASA/Mir Program: A Space Station Education" *http://mgnews.msfc.nasa.gov/winter98/mir.html.* For more information about ongoing research about the ISS, see http://spaceresearch.nasa.gov/research projects/ros/ros.html.

Shaken, Not Stirred *continued from page 15*

amount of bone mass already existing in the animals. However, bone mass itself is simply the phenotype, or physical manifestation, of the bone cells within the tissue (osteoblasts, osteoclasts, etc.), which are themselves controlled by genetics. "The cause of the differential sensitivity is likely the genetic variations — this is at the level of the cell, *not* the tissue — and not the amount of bone present, which, however, may serve as a surrogate indicator," explains Judex. "A flow chart might look like this: genetic variations, located in the cells, cause differential bone mass, which will in turn cause differential mechanosensitivity."

Judex's work on how the genetics of a particular organism such as a mouse or a human controls bone mass and affects bone's response to treatment is in the early stages. His discoveries will likely have a great impact on the ability of drugs to target bone-forming cells within problem areas of the skeleton. A better understanding of the control that genetics has over bone formation will also help scientists find better and more effective countermeasures for bone loss, both in space and on Earth.

Carolyn Carter Snare

For more information on Rubin's oscillating platforms, see *http://www.bme.sunysb.edu/bme/people/faculty/c_rubin.html* on the World Wide Web. For more information on Judex's genetics research, see Judex, S., Donahue, L., & Rubin, C. (2002, June 21). Genetic predisposition to low bone mass is paralleled by an enhanced sensitivity to signals anabolic to the skeleton. *Federation of American Societies for Experimental Biology Journal,* express article 10.1096/fj.01-0913fje. Abstract retrieved August 7, 2002, from *http://www.fasebj.org/cgi/content/abstract/01-0913fjev1.*

Meteorite Mystery *continued from page 19*

their solid lives as dendrites. Dendrite growth and pattern formation in general are critical elements in the production of everything from industrial metal structures like turbines to some biological systems. Gillies says the asteroid's long life should have given its structure time to grow nearly as large as it ever could, a state of equilibrium that cannot be duplicated in normal experiments. And information about the ultimate fate of dendrite formation could advance research on shorter timescales, he says. Both coarsening and dendrite growth have been much studied in NASA's materials science program.

Another reason researchers have long been interested in learning about the meteorite's metallic structure and the possibility that it is dendritic is that it could provide critical general information about how planetary bodies form. These bodies would include the Earth, whose core some researchers believe contains similar materials. There is ongoing debate, says Gillies, about whether the center of the Earth is in fact dendritic.

"The origins of the universe are still very mysterious to us. The status of our own planet is very mysterious to us," says Gillies. He and other researchers he is consulting with are hoping that solving some of the Mundrabilla meteorite mysteries will soon shed light on these elemental questions.

Mark Schrope

For more information on dendritic crystal growth, look on the World Wide Web at *http://mgnews.msfc.nasa.gov/IDGE/IDGE.html.* To see *Meteorite* magazine, go to *http://homepages.ihug.co.nz/~afs/index.html.* For more on Gillies's meteorite research, read Gillies, D. C. & Engel, H. P. Computer tomography support of materials science experiments. Paper AIAA 2001-5109, presented at the Conference on International Space Station Utilization, October 15–18, 2001, Kennedy Space Center, FL.

Plowing Space in the Classroom *continued from page 23*

English) educational space agriculture materials, technology-based activities, and teacher workshops. One technology-based activity exemplifies the program's hands-on approach by challenging students to build an effective clinostat, a device researchers use to simulate microgravity for biological experiments. The task is to create a structure that can rotate a plant specimen at a specific pace — that is, turning just fast enough that the plant does not detect the direction of gravity but slow enough that the wheel does not generate centrifugal force.

"The response has been phenomenal," says Gus Koerner, program manager for SAITC, "the teachers [attending workshops] are saying, 'Tell me more, tell me more — this is great material for my kids.'"

Other programs with a similar focus, such as NASA's Eco-Lab Space Program, BioBLAST, and Farming in Space (see sidebar), have been popular educational resources for years among biology teachers and students, but their distribution has been limited. "Space Agriculture in the Classroom will organize and legitimize these other groups under one umbrella, so to speak," says Koerner, "so we can get the material out to a broader audience in a more efficient manner."

Koerner works at the Biological Sciences Branch of Kennedy Space Center in Florida, where SAITC began. Through SAITC, NASA has partnered with the USDA-sponsored program called Agriculture in the Classroom (AITC), which serves almost 5 million students nationwide.

Almost every state, land-grant university, and county extension office acts as a resource center for Agriculture in the Classroom. For more than 20 years, AITC has helped students gain a greater awareness of the role agriculture plays in the economy and society. This knowledge will enable them to become citizens who are educated about agricultural policies and their impact.

SAITC targets similar objectives, yet with a focus on space. The program also encourages women, underrepresented racial and ethnic minorities, differently skilled individuals, and all other underserved groups to become active participants in space and agricultural sciences.

The University of Florida and the Florida Agriculture in the Classroom program have been working with Koerner for the past year and a half. In addition, AITC's lead partners in Utah, New Mexico, and Alabama will participate in SAITC's first year. Other states that have expressed interest are Indiana, Texas, and California.

"Kathleen Cullinan, the USDA Agriculture in the Classroom national program leader, and I are working closely to get this going," says Koerner. "The enthusiasm among the educators and the excitement across both agencies are high, and the program seems to be growing like a snowball rolling downhill."

Chris McLemore

For more information about Space Agriculture in the Classroom, go to *http://www.agclassroom.org/saitc.html* on the World Wide Web, or contact Gus Koerner by phone at (321) 867-8431 or by e-mail at *gus.koerner-1@ksc.nasa.gov.*

Profile: Chiaki Mukai

Chiaki Mukai is using the combination of her experiences as an astronaut, a physician, and an educator to share with people inside and outside of the classroom the phenomena that occur when people travel in space.

The moment that astronaut and physician Chiaki Mukai first saw Earth from space with her own eyes, her perspective on the world changed. And she found her own answer to a question that she had long contemplated: why do humans need to spend resources on space programs when the same money could be spent on Earth to save lives, feed the hungry, or ease suffering? She thought about the people on the continents she could see who must stay focused on today to survive and don't have the luxury of planning for tomorrow, and she reached her conclusion — it's *our* obligation to think about the *future*.

Mukai, who flew as a payload specialist for Japan's National Space Development Agency (NASDA) on STS-65 in 1994 and on STS-95 in 1998, explains, "If I am in the fortunate position that I can think about the future, which means education or research and development, I should. There are so many people who want to think about their future but can't. For example, the children who are right now in wartime countries — rather than think about their future dream, they have to think about whether they will have bread to eat tonight.

"So, if you or I or anyone is in a luckier position, we have to spend a little bit of money for the future rather than think only about the day."

For Mukai, who received doctorates in medicine and in physiology from the Keio University School of Medicine, two components of investing in the future are supporting education and utilizing space, and she often combines the two in her work. For example, during STS-95, Mukai conducted experiments with orchard grass seed embryos and cucumber seedlings in space while 6,000 elementary students conducted the same experiments on Earth, allowing them to see and understand the growth difference between the two environments. "The children wrote reports on the results, and we as a crew talked to the children after the flight via the Internet in an interactive way," says Mukai. "Even though [the children] did not go to space, they could still enjoy

credit: NASA

using that special environment to make them feel like they were a part of the crew."

Mukai also brings space experiences into the classroom on Earth. A cardiovascular surgeon, board-certified by the Japan Surgical Society in 1989, she has worked on the medical staffs of Keio University Hospital, Shimizu General Hospital, and Saiseikai Kanagawa Hospital. She also taught in the Department of Cardiovascular Surgery at Keio University. As a research instructor at the Baylor College of Medicine, Houston, Texas, and as a visiting associate professor at Keio University School of Medicine, she can describe firsthand physiological phenomena that space travelers experience when gravity's influence is minimized, such as the sensations of floating and of stuffy-headedness during flight as fluids shift upward in the body, as well as phenomena that occur upon returning to Earth's gravity, such as the heightened sensitivity of the neurological system that senses a single sheet of paper as a heavy weight on the hand it rests upon.

Mukai also supports education outside of the classroom. She speaks regularly on numerous physiological effects of spaceflight on humans, including changes to the cardiovascular system, the vestibular system, and the nervous system, at conferences supported by NASA's Office of Biological and Physical Research (OBPR), such as the annual American Society of Clinical Oncology conference and the biennial Pan-Pacific Basin Workshop. Mukai uses all of these venues to emphasize the importance of research in space. She explains, "After coming back from space, I realized how gravity masks the phenomena happening on Earth. I believe if you want to investigate the phenomena on Earth, you really have to first know the phenomena in a gravity-free environment."

In addition to promoting space as a location for research, Mukai supports many other uses of this unique environment: "Going to space to promote more research is one of my dreams, but the flight part is not the only dream of mine. I'm also interested in promoting the utilization program in space in not only research, but also other areas, such as music and literature.

"For a long time in our history, people have been creating wonderful arts — painting, music, literature — by their imagination toward space, or sometimes toward heaven, an unknown world above the clouds. Thanks to the development of the transportation system to and from space, space has become a part of our living environment. So many artists will be able to expand their artistic exploration more and more in this space age."

Mukai took advantage of the inspiration of being in space during STS-95 and wrote the first three lines of a tannka, a traditional Japanese poem:

In space, we can do
Somersault as much as we like,
Since it is weightlessness.

A complete tannka has five lines, and Mukai invited viewers of a broadcast downlink to complete the poem by creating the last two lines. She recalls, "We had about 145,000 responses from a variety of people including English-speaking people, children, and senior people over 90 years old. It was a great opportunity to share the feeling in space as well as a cherished Japanese traditional poem [form] with many people on the ground."

Mukai keeps her astronaut status active so if she is needed as a crewmember of the International Space Station, she'll be ready. In the meantime, she'll continue reaching as many people as she can to promote the wonders and various uses of space. She says, "Space is a common resource for everybody living on the Earth — same as sky, water, or air."

Julie Moberly

For more information, you can reach Mukai at *chiaki.mukai1@jsc.nasa.gov*.

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